BIOLOGY OF *Euseius mesembrinus* (ACARI: PHYTOSEIIDAE), INCLUDING PROGRAMS FOR LIFE TABLE CALCULATIONS AND A LOG-PROBIT MODEL FOR DEVELOPMENTAL TIME AND FINITE RATE OF INCREASE

By

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Abstract of Dissertation Presented to the Graduate School
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BIOLOGY OF *Euseius mesembrinus* (ACARI: PHYTOSEIIDAE), INCLUDING PROGRAMS FOR LIFE TABLE CALCULATIONS AND A LOG-PROBIT MODEL FOR DEVELOPMENTAL TIME AND FINITE RATE OF INCREASE

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Chairman: Dr. Harvey L. Cromroy
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Major Department: Entomology and Nematology

The primary objective of this study was to determine the biology and life tables of *Euseius mesembrinus* (Dean) (Acari: Phytoseiidae). Scanning electron micrographs are presented to illustrate taxonomic characters of *E. mesembrinus*.

Developmental times of *E. mesembrinus* immature stages fed pollen of *Malephora crocea* (Jacq.) at 18, 22, 26, and 30°C were 11.50, 7.47, 4.54, and 4.4 days, respectively. Eggs hatched, but mortality in subsequent stages was high at 34°C. The r_m values were 0.146, 0.250, and 0.246 at 22, 26, and 30°C with an optimum temperature range of 26 to 30°C.

Life tables were constructed for *E. mesembrinus* at 26°C and 75% relative humidity where immatures developed on *M. crocea* pollen and adult females were then provided one prey species or *M. crocea* pollen.

Eutetranychus banksi (McGregor), *Eotetranychus sexmaculatus* (Riley), and *Panonychus citri* (McGregor) were allowed to increase on modified citrus leaf arenas before introducing newly mature adult females of *E. mesembrinus*. The r_m values of *E. mesembrinus* (assuming 90% survival to adulthood under the experimental conditions) were calculated as 0.244, 0.199, 0.191, and 0.166 when adult females were provided *M. crocea* pollen or the immatures of *P. citri*, all stages of *E. banksi*, or *E. sexmaculatus*, respectively.

The prey type provided for *E. mesembrinus* adult females did not affect either progeny sex ratio or survival on *M. crocea* pollen as a food source. All motile stages of exposed tetranychid mites were attacked except the adult females of *P. citri*. Eggs of *P. citri* and *E. banksi* were not fed upon within the arena. Webbing produced by *E. sexmaculatus* effectively protected its eggs from predation by *E. mesembrinus*. *Phyllocoptruta oleivora* (Ashmead) was not a suitable prey.

Life 48 BASIC computer program was written to calculate life table parameters for an insect or mite species using age-specific distribution data following the method presented by Birch (1948).

A log-probit BASIC computer program was written to evaluate the goodness-of-fit of the relationship between temperature and developmental time or finite rate of increase of *E. mesembrinus*. Applying this model to published data over 10 years indicated a R^2 value of 0.94 (SD = 0.0242, n = 32), including both developmental time and finite rate of increase.

INTRODUCTION

The citrus rust mite, *Phyllocoptruta oleivora* (Ashmead) (Acari: Eriophyidae), the Texas citrus mite, *Eutetranychus banksi* (McGregor) and the citrus red mite, *Panonychus citri* (McGregor) (Acari: Tetranychidae) are important arthropod pests in Florida citrus.

P. oleivora is the most important arthropod pest of citrus in Florida, followed by *E. banksi* and *P. citri*. Both groups are present throughout the year, with the tetranychid mites occurring mainly in the spring and fall, while the citrus rust mite is most abundant in the summer (Childers 1987). The six-spotted mite, *Eotetranychus sexmaculatus* (Riley), is an occasional pest in late winter and spring especially after cold Decembers (Muma 1975).

Florida had 624,492 acres of citrus in 1986 (Florida Crop and Livestock Reporting Services 1986). This constituted 67% of the total United States production for the 1986-1987 season (Florida Agriculture Statistics Services 1988).

Florida citrus acreage reached a maximum in 1970 with 941,492 acres and declined to 624,492 acres in 1986 due to repeated freezes in 1983, 1985, and 1986. The main citrus production areas in Florida include the Indian River, the Upper and Lower Central Ridge, and Southern Florida with 172,513, 319,943, and 132,032 acres, respectively (Florida Crop and Livestock Reporting Services 1986).

Pesticides are used for control of *P. oleivora*, *E. banksi*, and *P. citri* in most commercial groves at different times of the year according to the population dynamics of each species. The cost for chemical control for mite pests, including application costs, in these three areas during 1987 was estimated at $153.72, $193.18, and $121.34 per acre, respectively, and averaged $141.46 per acre (Muraro 1987a,b, Muraro & Matthews 1987). Based on these estimates and the reported citrus acreage, the total cost for mite control on Florida citrus could be estimated at 70 million dollars a year for all mature citrus.

Biological control of mite pests on citrus should receive more attention in Florida to develop an additional pest management tactic.

Some phytoseiid mites feed on phytophagous mites and have a role in their natural control (McMurtry et al. 1970). The "Florida Phytoseiidae," compiled by Muma and Denmark (1970), is a large group represented by 86 species. Thirty-seven species were reported in association with citrus (Muma 1975). There is little known about the biology, food range, quantal distribution or biological control potential of phytoseiid mites on citrus in Florida.

Euseius mesembrinus (Dean) (Acari: Phytoseiidae) is a new predatory mite on Florida citrus (McCoy & Rakha 1985). It was suspected that *E. mesembrinus* was introduced into Florida from Texas where it was reported for the first time by Dean (1957).

Studying the biology of *E. mesembrinus* was the objective of this research. This step is important in understanding the predatory mite's role as a biological control organism. The ability of *E. mesembrinus* to feed, develop, and increase on plant pollen or tetranychid mite pests on Florida citrus was determined. In the first study, developmental time and life table parameters of *E. mesembrinus* at different constant temperatures using ice plant pollen, *Malephora crocea* (Jacq.) were studied.

In the second study, life table parameters of *E. mesembrinus* were constructed using *M. crocea* pollen or one of the tetranychid mite pests on Florida citrus (i.e., *P. citri*, *E. banksi*, and *E. sexmaculatus*).

During these studies, a BASIC computer program to calculate life table parameters according to Birch (1948) was developed and included. The data from developmental times and finite rate of increase of *E. mesembrinus* as well as published studies in relation to temperature were fitted to a Log-probit model using a BASIC computer program written for this purpose.

LITERATURE REVIEW

Euseius mesembrinus

The redefinition of the genus Euseius Wainstein by McMurtry (1983) included 60 or more species with relatively uniform morphology and biology. The cheliceral morphology and placement of setae on the ventrianal shield appear to be unique in the family Phytoseiidae and the combination of these features with the dorsal shield setal pattern results in a well-defined genus (McMurtry 1983).

E. mesembrinus was found in Texas in association with Oligonychus pratensis (Banks) on corn and sorghum leaves (Dean 1957). E. mesembrinus also was reported from Louisiana in 1975 (H. A. Denmark, personal communication 1984) and recently from Florida citrus (McCoy & Rakha 1985). Browning (1983) reported E. mesembrinus as the prevalent phytoseiid occurring on citrus in the Lower Rio Grande Valley area of South Texas throughout the year.

E. mesembrinus was first described in the genus Typhlodromus Scheuten as a new species of the finlandicus Oudemans complex by Dean (1957). A set of drawings of E. mesembrinus was obtained from Mr. Harold A. Denmark and is presented here. The dorsal setation of the E. mesembrinus female is shown following chaetotaxy nomenclature used by Lindquist and Evans (1965) in Fig. 1 A, Chant (1959) in Fig. 1 B, and Muma and Denmark (1970) in Fig. 1 C. The three systems are presented for comparative reference. Illustrations showing the taxonomic characters of E. mesembrinus are presented in Fig. 2.

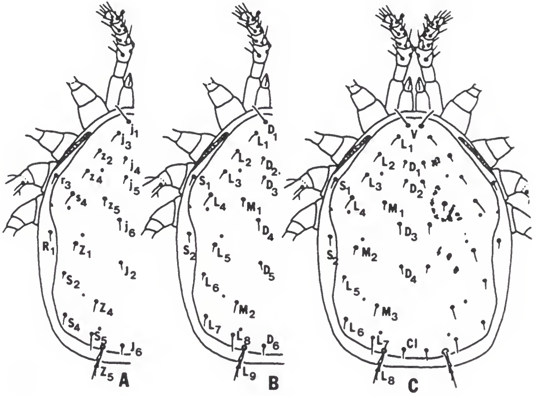

Figure 1. Dorsal setation of Euseius mesembrinus (Dean) (Female), following chaetotaxy nomenclature presented by: (A) Lindquist and Evans (1965), (B) Chant (1959), (C) Muma and Denmark (1970).

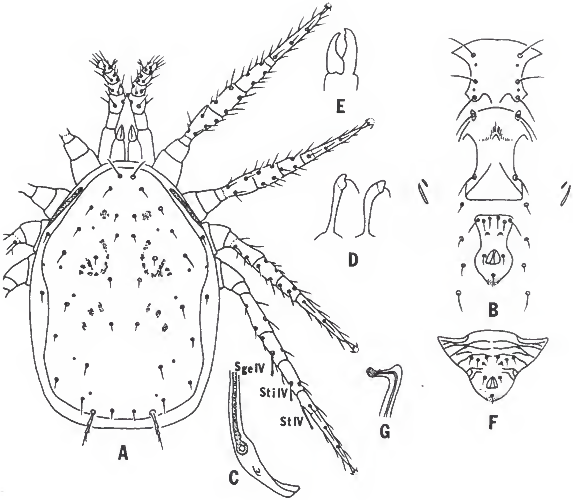

Figure 2. Taxonomic characters of Euseius mesembrinus (Dean). (A) Chaetotaxy of dorsal shield and legs (female), (B) Ventrianal scuta and setation (female), (C) Posterior peritremal and stigmatal development (female), (D) Spermathecal structure (female), (E) Cheliceral structure (female), (F) Ventrianal scutum (male), (G) Spermatodactyl structure (male). (Provided by H. A. Denmark)

The finlandicus group as described by Chant (1959) has a dorsal shield with 17 pairs of setae, nine in lateral rows (L_1-L_9). The ventrianal shield is usually nearly oval in outline, with margins rounded, convex, and with three pairs of pre-anal setae arranged in a transverse row across the anterior third of the shield. Only one pair of pre-anal setae is present on the margin of the shield. E. mesembrinus is identified in this group by having L_9 and D_1 moderately long, and the remaining setae are shorter or minute. Seta L_1 is approximately as long as L_3. Setae L_5 and L_6 are equal to one another. The ventrianal shield is oval but much longer than wide. Four pairs of setae are present on the membrane surrounding the ventrianal shield. Leg IV has three macrosetae which are slightly expanded and rounded distally rather than sharply pointed (Dean 1957, Chant 1959).

Biological and ecological studies have been conducted on related species in the genus Euseius including E. hibisci (Chant), E. citrifolius (Denmark and Muma), E. stipulatus (Athias-Henriot) and E. scutalis (Athias-Henriot) (McMurtry & Scriven 1964b, 1965a, Tanigoshi et al. 1981, Moraes & McMurtry 1981, Ferragut et al. 1987, Bounfour & McMurtry 1987). Most of these studies used a leaf arena with plant pollen as a food source. Previous studies indicated the ability of E. hibisci to feed and increase on pollen (McMurtry & Scriven 1964b, 1965a). Later, all studied species in the genus Euseius were found to be facultative pollen feeders with the ability to feed on some arthropod species (McMurtry 1983). The ability of E. hibisci to control a population of Oligonychus punicae (Hirst) under greenhouse studies was influenced by the availability of pollen as an alternate food source (McMurtry 1968).

Biological Control Successes with Phytoseiid Mites

Phytoseiulus persimilus Athias-Henriot has been successfully used in mass release programs to control Tetranychus urticae Koch in greenhouses in Europe. Galendromus occidentalis (Nesbitt) developed resistance to organophosphate insecticides such as azinphos methyl used for controlling the codling moth Cydia pomonella (L.). As a result, use of this predator was possible in apple IPM programs for controlling Tetranychus mcdanieli McGregor in the western United States (McMurtry 1982). G. occidentalis also feeds on apple rust mite, Aculus schlechtendali (Nalepa) which is an alternate prey when T. mcdanieli numbers are low. G. occidentalis did not effectively control the European red mite, Panonychus ulmi (Koch) (Hoyt and Caltagirone 1971). Similar IPM programs were developed in California for peach, pear, grapes, walnuts, and almond utilizing G. occidentalis (Flaherty & Huffaker 1970, Hoyt & Caltagirone 1971, Westigard 1971).

Neoseiulus fallacis (Garman) is widely distributed in North America and overwinters in ground cover vegetation. This predator moves into the trees and effectively suppresses P. ulmi as well as other spider mite species in various midwestern states. N. fallacis developed resistance to certain pesticides and was used in apple IPM programs in Illinois and Michigan (Meyer 1974, Croft 1976). N. fallacis was found to be the most abundant phytoseiid mite in Missouri apple orchards and effectively suppressed the tetranychid mites unless disturbed in early season by fungicides such as benomyl or sulfur (Childers & Enns 1975 a,b).

A resistant strain of Typhlodromus pyri Scheuten to certain pesticides was used as the main predator of P. ulmi on apple in New

York, New Zealand, and The Netherlands. T. pyri was found to feed also on A. schlechtendali (Gruys 1982).

E. hibisci was found to be the most common phytoseiid mite on California citrus and avocado and was considered an important factor in suppressing both E. sexmaculatus and O. punicae on avocado and P. citri on citrus in early spring. Euseius addoensis (van der Merwe and Ryke), Euseius elinae Schicha, and Euseius fructicolus Gonzalez and Schuster, are considered to be potentially important predators of P. citri on citrus in South Africa, Australia, and Chile, respectively (McMurtry 1982).

E. scutalis (Amblyseius gossipi El-Badry) in Egypt, Euseius concordis (Chant) in Brazil, and Typhlodromus rickeri Chant in California were reported to feed and develop on Eriophyes lycopersici (Wolffenstein), Aculops lycopersici (Massee) and P. oleivora, respectively (McMurtry & Scriven 1964a, Abou-Awad 1983, Moraes & Lima 1983).

Rearing of Phytoseiid Mites

Adequate environmental conditions and food sources are essential for successful mite rearing. Optimum conditions vary according to the mite species and important factors include temperature, light duration and intensity, humidity, proper food, and a rearing substrate. McMurtry and Scriven (1965b) indicated favorable humidity (ca. 80%) was extremely important for successful rearing of many phytoseiid mite species in the genera Amblyseius, Phytoseiulus, and Typhlodromus.

A suitable food source for tetranychid mites usually is a leaf or fruit surface. However, suitable food source(s) for phytoseiid mites may vary from plant pollen to specific arthropod or nematode species or combinations of these. To determine the intrinsic rate of increase of an insect or mite, food(s) must be provided which maximize development and reproduction. Ristich (1956) used infested bean leaves on saturated cotton in Petri dishes for rearing *N. fallacis*. Gilstrap (1977) reported a table-top rearing technique for tetranychid mites and their phytoseiid natural enemies using rooted lima bean leaves.

A technique for rearing *E. hibisci* on ice plant pollen, *M. crocea* was developed by McMurtry and Scriven (1964b). A lemon leaf arena was used by Moraes and McMurtry (1981) for rearing *E. citrifolius*. These methods were similar in using a leaf surface on a water-saturated cotton over a plastic foam bed. However, the high relative humidity hastened mold development in pollen that was used as food. Ice plant pollen was usable for 5 d as a food for the phytoseiid mites compared to 2 or 3 d for most other plant pollens tested in California. Some phytoseiid mites can be reared on an artificial surface while being fed tetranychid mites, whereas other phytoseiid mites require a leaf surface (McMurtry & Scriven 1965b). A rough natural substrate such as a leaf surface was found to favor oviposition by *Phytoseius hawaiiensis* Prasad more than a smooth tile surface (Sanderson & McMurtry 1984). Ingested plant sap may provide the phytoseiid mite with an alternate source of food and/or moisture (Porres et al. 1975). Munger and Gilmore (1963) used a leaf cage developed by Munger (1942) for individual studies of the citrus red mite. This structure was modified later by Tashiro (1967) and Swirski et al. (1967) as a self-watering acrylic cage. These units provided lower humidity than previously reported units and could use citrus leaf or fruit surfaces for rearing phytoseiid mites.

Life Table Parameters Calculation

Birch (1948) identified the life table parameters to be used in calculating insect population development by adapting human demography values. The primary population parameter was the intrinsic rate of natural increase (r_m) which fits the following approximation for an insect species under a definite condition:

$$\sum_{o}^{max} (L_x)\ (M_x) * \exp\ (-r_m * X) \cong 1 \qquad (1)$$

where: r_m = the intrinsic rate of natural increase, X = the female age, L_x = the fraction of females living from birth to age X, and M_x = the expected number of daughters produced per female alive at age X.

Birch (1948) provided both approximate and precise methods for calculating the value of r_m. The approximate method calculated the mean generation time (T), using Equation 2, then estimated the value of r_m using Equation 3.

$$T = \Sigma\ ((X)(L_x)(M_x))\ /\ R_o \qquad (2)$$

$$r_m = \ln\ (R_o)\ /\ T \qquad (3)$$

where: R_o = the net reproductive rate $[\Sigma\ ((L_x)(M_x))]$.

Birch (1948) tried different values of r_m to fit Equation 1 until the desired accuracy was obtained. Andrewartha and Birch (1954, p. 33) quoted, "We define r_m, the innate capacity for increase, as the maximal rate of increase attained at any particular combination of temperature, moisture, quality of food, and so on, when the quantity of food, space, and other animals of the same kind are kept at an optimum and other organisms of different kinds are excluded from the experiment."

Developmental Time and Temperature

Entomologists are interested in forecasting insect life history events. Predicting seasonal occurrence of insects or mites is essential for accurate scheduling of census sampling programs and control tactics. This prediction requires an understanding of an arthropod's developmental time, which is affected considerably by thermal factors that fluctuate continuously both daily and seasonally in the environment (Wagner et al. 1984). Mass rearing of beneficial insects also requires knowledge about optimal conditions for maximum production. Arthropods as poikilothermic animals are affected by environmental conditions including the temperature around them. Their development occurs only within a definite range of temperatures which may vary among species. This is referred to as "the favorable range," and it can be broad (i.e., terrestials) or narrow (i.e., aquatics) according to the species habitat (Andrewartha & Birch 1954). If developmental times are measured under constant temperature at close intervals within an insect's thermal tolerance range, a reverse "J"-shaped curve of time versus temperature results. The reciprocal of development times expressed as developmental rate (DR) or velocity also produces a shallow sigmoid ("S"-shaped) curve (Wagner et al. 1984). This occurs if the species does not go into dormancy with unfavorable temperatures.

The development rate curve asymptotically approaches the point of zero development under the lower thermal limits because insects often survive for long periods at low temperatures with little or no development. For this reason, the temperature at which development first occurs (i.e., the threshold) is difficult to measure accurately. As temperature increases from the lower limit, the development rate becomes proportional to temperature, and an approximate linear response curve results in the mid-region. Development begins to slow as optimal temperature (i.e., the temperature associated with the highest developmental rate is reached); thereafter, development declines sharply. More and more individuals die as temperature increases beyond the optimum, thus making the study of development difficult at high temperatures too.

The day-degree method (the linear model or approximation) assumes that an insect requires a minimal fixed amount of thermal energy units to develop from one stage to another. This idea was developed and used in plant production under greenhouse situations (Arnold 1959, 1960). This approximation could be accurate if we did not consider the two ends of the non-linear sigmoid curve suggested by Andrewartha and Birch (1954, p. 206) for the relationship between temperature and developmental rate in insects.

Huffaker (1944) reviewed the published literature about temperature dependent development rates in insects. He reported that the linear model has neither an empirical nor a theoretical base in a biokinetic scale and considered the catenary curve of Janisch (1932) as the most adequate mathematical expression for this relationship. Janisch's formula is a combination of two exponential curves as a symmetrical curve around the optimum temperature.

The day-degree method has been used widely by entomologists to discuss the developmental rates under constant temperature regimes in insects (Foster & Taylor 1975) and in mites (Tanigoshi et al. 1975a,b, 1981, Moraes & McMurtry 1981).

A simple logistic curve with a function to reverse its direction over the optimum temperature (topt) was used by Stinner et al. (1974).

As sophisticated statistical computer packages became available for non-linear regression, more complicated models were developed. Sharpe and DeMichele (1977) presented a reaction kinetics model for poikilothermic development with six parameters to be calculated by non-linear regression. Wagner et al. (1984) considered this model as the most accurate in determining the developmental rate at different temperatures.

The probit function (integration of the area under a normal distribution curve with a mean of 5 and variance of 1) is widely used to model a logistic relationship between stimulus and a quantal response in toxicology and biology. There are well known programs of this type for toxicology written in Fortran (Daum and Killcreas 1966, Daum 1970, Robertson et al. 1981, Russell et al. 1977). However, these programs are specifically intended for bio-assay. The probit function may be appropriate for modeling other systems showing sigmoid relationships.

MATERIALS AND METHODS

Scanning Electron Microscopy of Euseius mesembrinus

Specimens of male and female E. mesembrinus were collected in 80% alcohol. Scanning electron microscope (SEM) studies were conducted using a S450 Hitachi SEM at the Institute of Food and Agricultural Sciences' Ultrastructure Laboratory, Bartram Hall, University of Florida. Specimens were dehydrated according to Nation's (1983) technique, placed on stubs and then coated with gold using an Eiko 1B-2 ion coater.

Biology and Life Tables of Euseius mesembrinus at Different Temperatures on Ice Plant Pollen

Leaf Arena Method

The inverted lid of a 9 cm diam. plastic Petri dish was fitted with an absorbent cotton disc, lined with a filter paper, and saturated with deionized water. Water content was maintained daily by weight. Twelve 4 mm diam. holes were drilled in the cover (i.e., bottom half) of the Petri dish to allow air exchange and to prevent relative humidity from reaching saturation. Two clean mature grapefruit leaves, each 7 to 8 cm in length, were placed with the lower surface up on the saturated bed. Each leaf petiole was covered with saturated cotton to allow water uptake. The leaf edges were surrounded with a thin layer of Canada Balsam and castor bean oil (ratio: 1.5:1), using a fine brush. The barrier of Canada Balsam and castor bean oil was patterned after Swirski et al. (1967) since the saturated filter paper alone was inadequate in containing this mite. This provided an effective barrier to prevent the predatory mites from escaping. Ice plant pollen was supplied as food and cotton fibers were placed under cover slips for resting and egg laying sites (McMurtry & Scriven 1965b). For individual mite studies, the leaf surface was divided into three parts using the same barrier.

The units were held in an environmental chamber which provided constant temperature, fluorescent lighting, and air circulation. The relative humidity inside the chambers ranged between 50 and 80%. However, at 1 cm above the leaf surface inside the rearing unit, relative humidity ranged between 75 and 85% as measured by a thermocouple probe for temperature and humidity (Digi-Sense^{TM}). Light intensity was adjusted to provide ca. 30 µmol/sec/m^2 at the leaf surface with 12 hours of light per day (Shibles 1976) using a quantum sensor (Li-Cor model Li-185) photosynthetically active radiation meter.

Euseius mesembrinus Culture

The laboratory culture of *E. mesembrinus* used in this study originated from grapefruit and orange leaves collected from commercial groves located near Lake Alfred and Wauchula in central Florida during February and March, 1984. The culture was colonized on the underside of excised leaves from grapefruit, *Citrus paradisi* Macf. seedlings and held at 26°C. Specimens of this culture were identified as *E. mesembrinus* by Dr. J. A. McMurtry (University of California, Riverside) and Mr. H. A. Denmark (Department of Plant Industry, Gainesville, Florida). Ice plant, *M. crocea* flowers were collected daily from plants maintained in the greenhouse. The anthers were cut, frozen and used in mite feeding as needed. Ice plants were obtained from a culture plot maintained at the University of California, Riverside.

Ice plant pollen was evaluated in California for rearing E. hibisci and found to be a suitable and preferred food source (McMurtry & Scriven 1964b, Tanigoshi et al. 1981). Use of the same pollen in these studies provides better comparison of results with other species in the genus Euseius. Pollens from different plant species do not have the same nutritional value and the intensity of pollen production may vary (Baker & Baker 1979). The pollen must store well and preferably have a low water content to minimize mold formation when used as a food source for mite rearing.

Developmental Time

Development of the eggs was observed daily at 0600, 1400, and 2200 hours until the males reached maturity or each female deposited its first egg. The quiescent stage and subsequent molt following each motile immature life stage was averaged with the preceding motile stage. Development time was calculated as half the time interval between observations as average duration.

Life Table Parameters Calculation

Twenty newly mated females were confined individually at 22, 26, and 30°C to study age-specific fecundity rates. A cohort of 50 eggs from each temperature-group was collected at 8 h intervals for individual developmental time studies. Newly deposited eggs from the main culture (held at 26°C) were collected at 8 h intervals and held at 18 and 34°C to study development. Life table parameters as defined by Birch (1948) were calculated using the Life 48 BASIC computer program (Appendix A).

Biology and Life Tables of Euseius mesembrinus Feeding upon Various Phytophagous Mites

A main concern in this study was to simulate natural conditions during the spring when different types of pollen are available in the field. This should allow a population of *E. mesembrinus* to increase before the tetranychid mites increase. For this reason, immatures were maintained on ice plant pollen when life table studies were conducted. Life table studies were undertaken to compare the ability of *E. mesembrinus* to increase when adult females were allowed to feed on different phytophagous mites at constant temperature and relative humidity.

Modified Leaf Arena

In this study the leaf arena method was modified by attaching another Petri dish bottom under the previously described unit as a water holder. A wick was provided for continuous saturation of the cotton pad (Fig. 3). Newly hardened leaves from sweet orange, *Citrus sinensis* [L.] Osbeck 'Hamlin' were used in the arenas during this study. Each leaf was fastened at its tip and base to the arena surface using adhesive tape to keep it flattened on the water saturated bed. The upper or lower leaf surface was used depending upon the natural distribution of the specific tetranychid mite species (i.e., upper leaf surface for *P. citri* and *E. banksi*, or lower leaf surface for *E. sexmaculatus*).

The units were held in an environmental chamber at 26°C. Relative humidity inside the chambers was maintained at 75 ± 5% using a saturated solution of NaCl (Winston & Bates 1960). All experiments were conducted under complete darkness as this appeared to favor rearing of *E. sexmaculatus*.

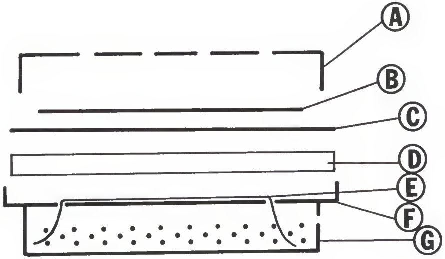

Figure 3. Diagram of rearing unit. (A) Plastic Petri dish cover, (B) Plant leaf or disc, (C) Filter paper, (D) Absorbent cotton, (E) Filter paper wick, (F) Base (plastic Petri dish lid), (G) Water container (plastic Petri dish cover).

Euseius mesembrinus Culture

The laboratory culture of *E. mesembrinus* used in this study originated from orange leaves collected in Winter Haven, Florida during April 1987. The culture was maintained on ice plant pollen. Eggs from the main predator culture were collected over a 12 h period and reared on a new leaf arena. Immatures were fed ice plant pollen.

Phytophagous Mite Species Cultures

P. citri adult females were collected from a greenhouse infestation. Each arena was infested with 25-30 adult females which were removed after 5-6 d. *P. citri* eggs developed in 5 d to the larval stage. Arenas with *P. citri* immature stages were incubated for 2 more days before being used as food for *E. mesembrinus* mated females. All life-stages of *E. banksi* were collected daily from infested citrus leaves and added to the leaf arenas as needed. A laboratory culture of *E. sexmaculatus* was maintained on leaves using the leaf arena method. This species was allowed to develop and produce webbing on the leaf arenas for 10 d prior to introduction of *E. mesembrinus* mated females. This was sufficient time for *E. sexmaculatus* to establish high population densities. *P. oleivora* were transferred to the test arenas from infested leaves. Humidity was kept near saturation around the leaf arenas by adding free water to maintain survival of *P. oleivora*.

Life Table Parameters Calculation

For age-specific distribution, mated female mites between 5.25 to 5.5 ± 0.25 d old were transferred to arenas infested with one of the tetranychid mite species. Five newly mated females were transferred to each of four arenas, per food type (i.e., total of 20 females). Egg laying and survivalship were recorded daily. New arenas infested with the phytophagous mite species were replaced at 3-5 d intervals or as needed.

Immatures Survival and Sex Ratio

The effect of food type on the survival and sex ratio of *E. mesembrinus* progeny was studied. A batch of 90 eggs from females that fed upon each food type was collected and allowed to develop within six leaf arenas (i.e., 15 eggs per arena) with ice plant pollen as food. Survivalship and sex ratio were determined after 5 d. The same method was used to determine survivalship of *E. mesembrinus* immatures that fed on tetranychid mites. Larvae from eggs laid by females feeding on ice plant pollen were allowed to develop on pollen only, immatures of *P. citri* only, *P. citri* with pollen, *E. banksi* only, *E. banksi* with pollen, and *E. sexmaculatus* only. The obtained results were analyzed statistically using the (ANOVA) procedure in the Statistical Analysis System (SAS Institute 1985).

Life 48: BASIC Computer Program for Calculation of Life Table Parameters

The techniques used by Birch (1948) were used in this program. The program first calculates X, Mx, Lx, (Mx)(Lx), and (X)(Lx)(Mx) for each interval using the input data. Applying Equations 2 and 3, the approximate r_m value is calculated. For each interval, the product of (Mx)(Lx) is then divided by the value of e raised to the power of $[(r_m * X)]$ to obtain the value of $[(Mx)(Lx) * \exp -(r_m * X)]$ as RML for each interval. The sum of RML over all the intervals is compared to the range of 0.9995 to 1.0005. If the sum of RML is not in that range, then the program reduces or increases the value of r_m by 0.0001 and executes the calculation again in a loop until the sum of RML reaches the indicated range. The last trial r_m value is considered the precise value.

The output of this program will be stored in a file (to be named by the operator). This file includes the following information for each interval of adult female age: total progeny per interval (M), number of females alive at age X (L), mean female age at each interval mid-point (X), female progeny per female (Mx), rate of survival (Lx), the product of [(Mx)(Lx)] as (MxLx), and the final values of RML to meet the original formula (Equation 1). Finally, the program prints the precise life table parameters of that study as the sum of RML, the net reproductive rate (R_o), the generation time (T), the intrinsic rate of natural increase (r_m), and the finite rate of increase (exp r_m).

This BASIC computer program uses either original life history data or precalculated Mx and Lx values. The program accepts the insect or mite name, temperature used, number of intervals, type of interval used, and asks for the data type. If the operator selects (1), the program will ask for the initial number of females, developmental time of immature females, proportion that reached maturity from the original progeny, sex ratio (assuming that it is stable during the progeny time), total fecundity per interval, and the number of females alive at each interval. If the operator selects (2), the program will ask for the precalculated (Mx) and (Lx) values for each interval instead of (M) and (L) values. The program was developed to run on DEC VAX minicomputers or IBM PC compatible microcomputers. Listing of the BASIC program is presented in Appendix A. This program was used in the calculation of the life table parameters of _E. mesembrinus_.

A Log-probit Model for Developmental Time and Finite Rate of Increase in Relation to Temperature

In this study, the relationship between temperature and both the individual developmental time and finite rate of increase was analyzed as a Normal sigmoid curve. This relationship can be linearized through the Log-probit treatment.

A BASIC computer program presented here was developed using the probit equation and tables published by Bliss (1935) and Finney (1952). This computer program was written to recalculate the correlation between temperature and developmental time or finite rate of increase for a mite species using published data as a Log-probit linear model using Equation 4.

$$\text{probit } Y = a + b \ln X \qquad (4)$$

where Y = developmental time or finite rate of increase, a = constant, b = slope, and X = temperature °C.

Temperature was considered the stimulus (X) to be transformed to ln X, and developmental time or finite rate of increase the response (Y) to be transformed to a probit value.

An integration method was developed for the probit calculation and is used here to transform the responses as percent to the corresponding probit and vice versa. The program was provided with definite probits and their corresponding percent values to reduce working time. A main function of this program was to transform the input data to the appropriate form. Transforming the response data (developmental time (DT)) or finite rate of increase (exp r_m) to percent required dividing by an estimated base which varied with the mite species. This transformation was essential to use the Log-probit treatment. This program rounded the highest value in the input response data and used it as the first estimated base. The program then calculated the regression parameters and the goodness-of-fit as the coefficient of determination (R^2). A gradual increment in the base value resulted in an increase of the calculated R^2 until a maximum was reached. The program increased the calculated base by 10% of the first estimated base value and recalculated a new R^2 value. The program iterated these calculations until the maximum R^2 value was obtained and the corresponding base value was selected. To obtain the expected values, the program calculated the expected probit first using Equation 4, then the expected percent response. Using the estimated base, the percent response was transformed to the expected value. The program (Appendix B) was developed to run on a DEC VAX minicomputer or on an IBM PC or compatible microcomputer.

The user is prompted for information about the type of response, either "DT" for developmental time or "r_m" for intrinsic rate of natural increase (r_m). The program was developed to accept (r_m) values because it is the base to calculate (exp r_m). The user then inputs the number of temperatures used and the data as pairs of temperature and response values. If DT was the response, then (the developmental rate (DR)) is used in the regression calculations for the day-degree method. For r_m type data, exp r_m was used.

The printout contains the input data, the calculated and expected values, the regression equation and the determination factor for the day-degree method and the proposed model. The printout also includes the expected values using the proposed model at specified temperatures.

A literature search for studies of developmental time or finite rates of increase for mites in the families Phytoseiidae and Tetranychidae over the past 10 years was completed. Only studies including four or more constant temperatures were selected (Table 1). Data from each study were analyzed using the Log-probit linear model. Less than four response values provided a poor R^2 value to this model.

Table 1. References of selected data for mite species in the families Phytoseiidae and Tetranychidae used for Log-probit model validation

No.	Author		Mite species	No. cons. temp.	Temp. range °C
			Developmental time of Phytoseiidae		
1.	Aponte	1980	*Amblyseius colimensis* Aponte	6	17.5 - 30
2.	Badii	1981	*Nesoseilus longipes* (Evans)	4	20 - 35
3.	Charlet & McMurtry	1977	*Metaseiulus validus* (Chant)	4	18 - 35
4.			*Typhlodromina pini* (Chant)	4	13 - 29
5.	Hamamura et al.	1976	*Phytoseiulus persimilis* Athias-Henriot	8	15 - 32.5
6.	Lo & Ho	1979	*Nesoseilus longispinosus* (Evans)	4	20 - 35
7.	Mahr	1978	*Typhlodromina arborea* (Chant)	4	15 - 30
8.			*Typhlodromina arborea* (Chant)	4	15 - 30
9.			*Typhlodromina johnsoni* (Mahr)	5	15 - 35
10.			*Typhlodromina citri* (Garman & McGregor)	5	15 - 35
11.			*Typhlodromina citri* (Garman & McGregor)	5	15 - 35
12.	Moraes & McMurtry	1981	*Euseius citrifolius* (Denmark & Muma)	4	15 - 30
13.	Sheriff	1982	*Amblyseius andersoni* (Chant)	4	15 - 30

Table 1. Continued

No.	Author		Mite species	No. cons. temp.	Temp. range °C
14.			*Galendromus longipilus* (Nesbitt)	5	15 - 35
15.			*Galendromus occidentalis* (Nesbitt)	5	15 - 35
16.			*Neoseiulus fallacis* (Garman)	5	15 - 35
17.			*Neoseiulus mckenzei* Schuster & Prichard	5	15 - 35
18.			*Neoseiulus umbraticus* (Chant)	4	15 - 30
19.	Tanigoshi et al.	1975a	*Galendromus occidentalis* (Nesbitt)	7	18 - 35
20.	Tanigoshi et al.	1981	*Euseius hibisci* (Chant)	7	18 - 35
21.	Abou-Setta & Childers	1987	*Euseius mesembrinus* (Dean)	4	18 - 30
			Developmental time of Tetranychidae		
22.	Hazan et al.	1973	*Tetranychus cinnabarinus* (Boisduval)	4	19 - 35
23.			*Tetranychus cinnabarinus* (Boisduval)	4	19 - 35
24.	Ho & Lo	1979	*Tetranychus urticae* Koch	4	20 - 35
25.	Tanigoshi et al.	1975b	*Tetranychus mcdanieli* McGregor	9	10 - 38
26.	Yasuda	1982	*Panonychus citri* (McGregor)	6	12 - 32

Table 1. Continued

No.	Author		Mite species	No. cons. temp.	Temp. range °C
			Finite rate of increase of Phytoseiidae		
27.	Lo & Ho	1979	*Galendromus* *longispinosus* (Evans)	4	20 - 35
28.	Tanigoshi et al.	1975a	*Galendromus* *occidentalis* (Nesbitt)	7	18 - 35
29.	Tanigoshi et al.	1981	*Euseius* *hibisci* (Chant)	7	18 - 35
			Finite rate of increase of Tetranychidae		
30.	Hazan et al.	1973	*Tetranychus* *cinnabarinus* (Boisduval)	4	19 - 35
31.			*Tetranychus* *cinnabarinus* (Boisduval)	4	19 - 35
32.	Tanigoshi et al.	1975b	*Tetranychus* *mcdanieli* McGregor	7	18 - 35

RESULTS AND DISCUSSION

Scanning Electron Microscopy of Euseius mesembrinus

The morphological characteristics of *E. mesembrinus* presented by Dean (1957) and illustrated by H. A. Denmark (Fig. 2) are shown using the SEM. The dorsal shield of the adult female (Fig. 4 A), the ventral plates of the female and the male (Figs. 4 B and C), and the macroseta on the genu of leg IV (Fig. 4 D) are shown to be in agreement with the original description (Dean 1957, Chant 1959) and Fig. 2.

Biology and Life Tables of Euseius mesembrinus at Different Temperatures on Ice Plant Pollen

Leaf Arena Method

The leaf arena method was used successfully in the rearing of *E. mesembrinus*. Ice plant pollen was usable for 10 to 15 d as food for *E. mesembrinus* between 18 and 30°C using this technique compared to 5 d for the same pollen in California (McMurtry & Scriven 1964b). The longer availability of an acceptable food source reduced handling time and disruption of individual mites. The following mites were reared using mature citrus leaves in this unit: *T. urticae*, *Tetranychus tumidus* Banks, *E. banksi*, *P. citri*, *E. mesembrinus*, and *E. hibisci*. At 26°C or less, mature citrus leaves were maintained in the unit up to 8 weeks unless fed upon by phytophagous mites. Leaf discs could not be maintained for as long as whole citrus leaves. However, enough time

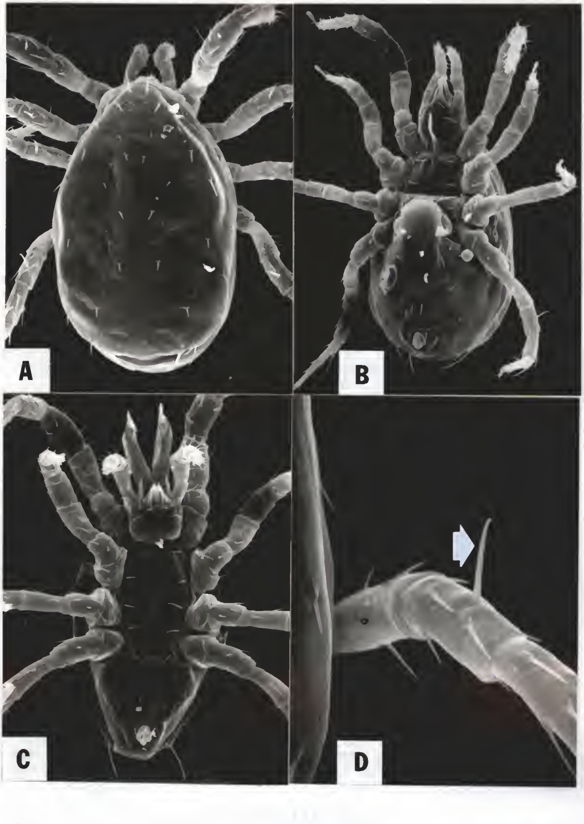

Figure 4. Scanning Electron Micrographs of Euseius mesembrinus (Dean). (A) Dorsal shield (adult female), (B) Ventral shields (adult female), (C) Ventral shields (adult male), (D) Macroseta on genu of leg IV.

elapsed (i.e., 14 d) for mites to complete a generation without changing the plant material.

Behavior and Feeding Observations of Euseius mesembrinus

E. mesembrinus is a typical phytoseiid mite, developing through egg, larva, protonymph, deutonymph, and adult stages for both sexes. The larval stage can feed on pollen or tetranychid mite eggs and larvae. *E. mesembrinus* was able to develop to maturity and reproduce utilizing a wide range of food substances under laboratory conditions. Food sources included pollen of Spanish needle, *Bidens pilosa* L., pollen of ice plant, *M. crocea*, all stages of *T. urticae*, *E. banksi*, and larval and nymphal stages only of *P. citri*. *E. mesembrinus* stages were not able to feed on the egg or adult female stages of *P. citri*. The color of this fast moving phytoseiid mite from either field samples or the pollen-fed culture was waxy white. Individuals that fed on tetranychid mites varied in color from yellow to dark brown. Development to the protonymph stage occurred on citrus leaves when no other food was available. Cannibalism was observed when food was scarce. Mature stages tried to feed on younger stages excluding the egg stage.

Mating was essential for egg laying and occurred as early as a few hours after maturity. Females mated once or several times before oviposition began. Males were observed attempting to mate with adult females of any age.

Influence of Temperature on Developmental Time

Duration (in days) of immature stages of *E. mesembrinus* fed ice plant pollen are presented in Table 2. At 34°C, the egg stage was able to develop while other stages incurred high mortality. *E. scutalis* suffered high mortality at 35°C (Bounfour & McMurtry 1987). Total developmental time for *E. mesembrinus* was almost equal in both sexes.

Table 2. Duration (days) of different stages of *Euseius mesembrinus* (Dean) at static temperatures

Temp	Female					Male				
°C	Min	Max	Mean	SD	N	Min	Max	Mean	SD	N
Egg										
18	3.00	4.00	3.64	0.35	11	3.00	4.67	3.81	0.33	20
22	2.00	2.80	2.44	0.25	27	2.33	2.83	2.35	0.25	13
26	1.00	1.90	1.48	0.35	18	1.25	2.00	1.78	0.19	18
30	1.00	1.70	1.38	0.25	25	1.00	1.67	1.45	0.19	16
Larva										
18	2.00	3.00	2.49	0.47	11	1.67	3.67	2.33	0.53	20
22	1.00	2.00	1.28	0.28	27	1.00	1.33	1.18	0.18	13
26	0.67	1.33	1.00	0.12	28	0.75	1.46	0.92	0.19	30
30	0.67	1.33	0.91	0.23	25	0.50	1.33	0.89	0.25	16
Protonymph										
18	1.92	3.33	2.71	0.25	11	1.83	4.33	2.70	0.63	20
22	1.00	2.33	1.70	0.37	27	1.00	1.83	1.27	0.30	13
26	0.83	1.17	1.05	0.14	28	0.92	1.50	1.05	0.19	30
30	0.67	1.67	1.03	0.22	25	0.67	1.67	1.10	0.35	16
Deutonymph										
18	1.92	3.00	2.67	0.47	11	1.92	3.92	2.65	0.58	20
22	1.33	3.50	2.05	0.65	27	1.00	2.17	1.60	0.43	13
26	0.83	1.33	1.01	0.07	28	0.67	2.00	1.05	0.12	30
30	0.67	1.33	1.08	0.15	25	0.67	1.67	1.10	0.29	16

Developmental times (mean days ± SD) for females were 11.51 ± 0.792, 7.47 ± 0.837, 4.54 ± 0.402, and 4.40 ± 0.432 at 18, 22, 26, and 30°C, respectively.

Duration of the egg stage was the longest and required 33% of total developmental time. The other three immature stages required ca. equal developmental times from the remaining interval.

Longevity, Fecundity, and Life Table Parameters

Life table parameters at 22, 26, and 30°C showed that this mite reached maximum adult longevity for 50% of the population at 26°C in 29.1 d. The highest net rate of reproduction (R_o) was 16.6 per female also at 26°C (Table 3). The time for 50% mortality was 26.0 and 23.4 d at 22 and 30°C, respectively, and the corresponding (R_o) values were 9.01 and 9.15. The preoviposition period and generation time (T) declined as temperature increased from 22 to 30°C. The intrinsic rate of natural increase (r_m) values were 0.146, 0.250, and 0.246 at 22, 26, and 30°C, respectively. The age-specific fecundity rate (M_x) and survivalship curve (L_x) for the tested temperatures are shown in Fig. 5. The computer printouts for life table calculations are presented in Appendix C.

The developmental time declined as temperature increased from 18 to 30°C with the optimal range occurring between 26 and 30°C. No significant reduction in developmental time occurred in this range. Applying the Log-probit model to this mite data yielded an $R^2 = 0.940$ for total developmental time. The range of regression R^2 values for immature stages was 0.880 to 0.989 (Table 4). The regression values and the expected developmental time for each stage and the total female developmental time at selected temperatures using this model are also

Table 3. Effect of temperature on the life table parameters of Euseius mesembrinus (Dean)

Parameter	Temperature		
	22°C	26°C	30°C
Developmental time (days)	7.47	4.54	4.40
Preoviposition period (days)	2.60	1.63	1.68
Time to 50% mortality (days)	26.00	29.10	23.40
Mean total fecundity (eggs/♀)	13.35	33.10	15.00
Net reproductive rate (R_o)	9.01	16.55	9.15
Generation time (T)	15.04	11.23	9.01
Intrinsic rate of increase (r_m)	0.146	0.250	0.246
Finite rate of increase (exp r_m)	1.157	1.284	1.279
Sex ratio (Females/Total)	0.675	0.500	0.610

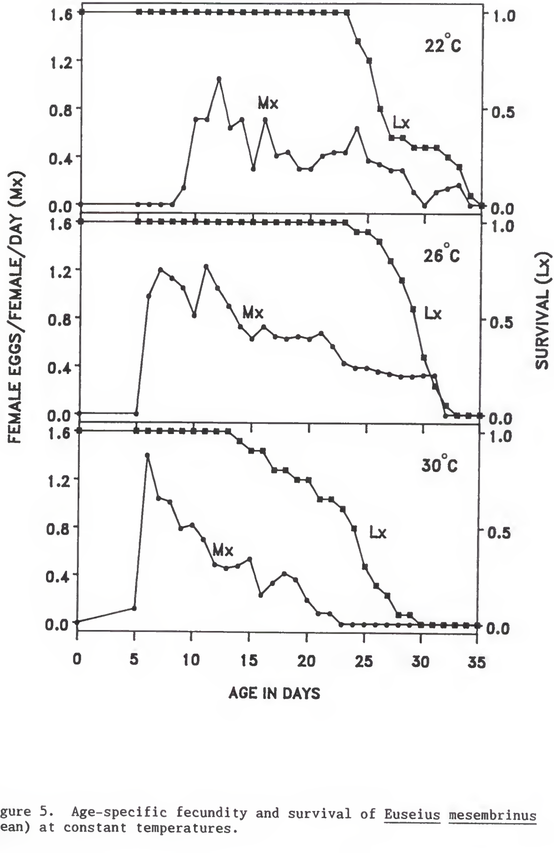

Figure 5. Age-specific fecundity and survival of Euseius mesembrinus (Dean) at constant temperatures.

Table 4. The results of applying the Log-probit model for developmental time to different stages of *Euseius mesembrinus* (Dean)

Stage	Regression values			Expected developmental time (days)					
	R^2	a_o	b	10°C	20°C	25°C	30°C	35°C	37°C
Egg	0.956	6.69	-1.03	8.88	2.91	1.86	1.24	0.87	0.76
Larva	0.986	6.22	-0.94	5.70	1.83	1.17	0.80	0.56	0.49
Protonymph	0.935	6.53	-1.00	6.54	2.11	1.34	0.90	0.63	0.55
Deutonymph	0.880	6.364	-0.97	6.90	2.20	1.41	0.95	0.66	0.58
Total	0.940	8.141	-1.33	24.1	9.13	5.84	3.85	2.60	2.24

included (Table 4). The computer printouts for these calculations are presented in Appendix D.

Similar observations for the developmental time of *E. citrifolius* were reported by Moraes and McMurtry (1981). Tanigoshi et al. (1981) reported 35°C as the optimum developmental temperature for *E. hibisci* on ice plant pollen. They indicated that the larval stage incurred high mortality at 38°C. Their conclusion depended on using the linear model between temperature and developmental velocity. Applying the Log-probit to their results indicated that a lower range of temperatures (i.e., 28 to 30°C) would be considered as optimum.

The finite rate of natural increase (exp r_m) of *E. mesembrinus* followed the Log-probit model with $R^2 = 0.756$ (which is relatively low because of the low number of temperatures tested). This model indicated 15.1°C as the lower threshold temperature for this species to increase (where the estimated exp $r_m = 1$ or $r_m = 0$).

The thermal tolerance range of temperatures for this species (18-30°C) seemed to be less than that indicated for *E. hibisci* (18-35°C) by Tanigoshi et al. (1981).

Biology and Life Tables of Euseius mesembrinus Feeding upon Various Phytophagous Mite Species on Florida Citrus

E. mesembrinus females that developed on ice plant pollen were mature at the age of 4.5 ± .25 d and their bodies were dorsoventrally flattened during this interval. Preliminary tests determined that changing the type of food at this age (4.5-5 d) caused high mortality of the female predators. Females were allowed to mate and their bodies became inflated by the fifth day. Egg laying did not occur before the sixth day of age.

Feeding Behavior on Different Tetranychid Mites

P. citri adult females attached their eggs directly to the leaf surface. They also produced some webbing although not as extensively as *E. sexmaculatus*. *P. citri* females did not lay eggs on their webbing and the webbing restricted egg laying by other *P. citri* females. However, adult female *E. mesembrinus* used this webbing to deposit their eggs. *E. mesembrinus* adult females fed on the larval and first nymphal stages of *P. citri* and did not feed on the egg or adult female stages.

E. banksi has egg laying behavior similar to *P. citri*, but produces very little webbing on the citrus leaf surface. *E. mesembrinus* adult females were able to feed on all stages of *E. banksi* except the egg stage.

E. sexmaculatus form dense colonies on the lower leaf surface of citrus. After the females lay eggs on the leaf surface, considerable web production occurs which provides more vertical substrate for additional eggs in the same area. In addition, this webbing provides the spider mite life stages with a protective cover (Gerson 1979). The webbing produced by *E. sexmaculatus* prevented entry by *E. mesembrinus*. No feeding on the egg stage was observed when protected by webbing. Adult females of *E. mesembrinus* were observed in the laboratory to move restlessly over the upper surface of the webbing while hunting for available motile stages of *E. sexmaculatus*. *E. mesembrinus* females laid their eggs on the web surface. In field samples, *E. mesembrinus* individuals were observed to congregate around the colonies apparently waiting for prey.

Behavior of *E. mesembrinus* towards the extensive webbing produced by some tetranychid mites was similar to studies conducted on other species in the genus *Euseius* (Moraes & Lima 1983). The same behavior for feeding on P. citri was reported for E. hibisci (McMurtry & Scriven 1964b, 1965a, Tanigoshi et al. 1981).

Longevity, Fecundity, and Life Table Parameters

Life table parameters of E. mesembrinus adult females feeding on ice plant pollen, P. citri, E. banksi, or E. sexmaculatus were reported in Table 5. The intrinsic rate of natural increase (r_m) was calculated as 0.244, 0.199, 0.191, and 0.166 and net reproductive rates (R_o) of 10.40, 10.67, 6.36, and 5.00, respectively. Age-specific fecundity and survival curves are shown in Fig. 6. The computer printouts for life table calculations are presented in Appendix E.

The rate of survival (L_x) and the expected female progeny per adult female (M_x) feeding on either ice plant pollen or P. citri immatures was higher than feeding on E. banksi or E. sexmaculatus (Table 5). The obtained r_m value on this food was superior to the values obtained for the tetranychid mites tested. The maximum R_o value per E. mesembrinus female was obtained on P. citri as prey compared with other food types used (Table 5). This R_o value did not reflect the highest r_m value because a longer generation time (T) on P. citri compared to feeding on ice plant pollen (Table 5). However, it suggests that E. mesembrinus has better ability to increase on and subsequently regulate a population of P. citri than either of E. banksi or E. sexmaculatus under the same conditions. Maximum fecundity of 2.5 and 3.7 eggs/female/d was reported for E. scutalis at 25 and 30°C, respectively (Bounfour & McMurtry 1987).

Egg laying by E. mesembrinus adult females over the first 10 d of the oviposition period was compared on various types of food (Table 6). This period was selected because most of the eggs were laid over this time by females provided with different types of food. The exception

Table 5. Effect of food type on the life table parameters of *Euseius mesembrinus* (Dean) at 26°C when immatures developed on ice plant pollen and adults were exposed to different food types

Parameter	Type of food			
	M. crocea	*P. citri*	*E. banksi*	*E. sexmaculatus*
Time to 50% mortality (days)	37.50	35.75	13.25	14.50
Mean total fecundity (eggs/♀)	22.60	23.65	12.44	11.16
Net reproductive rate (R_o)	10.40	10.67	6.36	5.00
Generation time (T)	9.58	11.89	9.68	9.72
Intrinsic rate of increase (r_m)	0.244	0.199	0.191	0.166
Finite rate of increase (exp r_m)	1.28	1.22	1.21	1.18

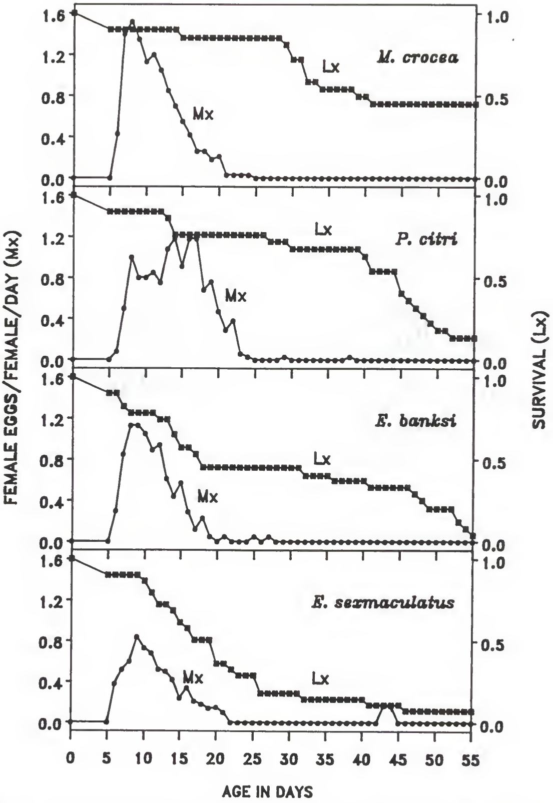

Figure 6. Age-specific fecundity and survival of Euseius mesembrinus (Dean) at 26°C and 75% RH, feeding on ice plant pollen and different tetranychid mites.

Table 6. Mean oviposition rate of Euseius mesembrinus (Dean) adult females over the first 10 days of the oviposition period on various foods

	Eggs per female				Percent
Type of food	Mean[a]	S.E.	Max.	N[b]	survival
Malephora crocea	2.035 a	.129	3.40	20	95
Panonychus citri	1.528 b	.102	2.75	20	85
Eutetranychus banksi	1.558 b	.137	3.00	20	50
Eotetranychus sexmaculatus	1.210 c	.129	2.20	20	65

[a] Means not having the same letter are significantly different ($P \leq 0.05$; ANOVA procedure [SAS Institute 1985]).

[b] Five females/arena in four arenas.

was when P. citri immatures were provided as food source. Most of the eggs were laid over a 15 d period in this instance. Feeding on ice plant pollen stimulated oviposition earlier than other types of food and reached a maximum of 3.4 eggs/female/d during the first 10 d of oviposition period (Table 6).

Immatures Survival and Progeny Sex Ratio

Survival of E. mesembrinus immatures produced by females exposed to different food types was not significantly different from each other when allowed to develop on ice plant pollen (Table 7). The type of food which the females were exposed to did not affect the sex ratio of their progeny or percent survival except on E. sexmaculatus (Table 7). Thus the ratio of 0.5 female/total was used in constructing all of the life table calculations.

E. mesembrinus immatures were able to survive and develop on tetranychid mites with or without ice plant pollen. Survival of immatures was significantly higher when provided ice plant pollen compared to feeding on specific tetranychid mites only or a combination of tetranychid mites and ice plant pollen (Table 8). It was observed that E. mesembrinus immatures fed upon P. citri immatures in the presence of pollen as determined by gut coloration.

Presence of pollen with P. citri or E. banksi stages increased survival, but the differences were not significant (Table 8). P. citri was a better food source for the development of E. mesembrinus immatures than E. banksi in the presence or absence of pollen. Newly hatched larvae of E. mesembrinus attempted to escape from arenas containing only E. banksi as the food source resulting in high mortality. Tanigoshi et al. (1981) reported 7% survival for E. hibisci

Table 7. Effect of *Euseius mesembrinus* (Dean) adult female's food type on survival and sex ratio of progeny fed ice plant pollen

Type of food	Percent survival	Sex ratio[a]
Malephora crocea	90.9 a	0.503 a
Panonychus citri	87.8 a	0.561 a
Eutetranychus banksi	90.9 a	0.544 a
Eotetranychus sexmaculatus	74.5 b	0.482 a

[a] Means in the same column not having the same letter are significantly different ($P \leq 0.05$; ANOVA procedure [SAS Institute 1985]).

Table 8. Effect of food type on survival of Euseius mesembrinus (Dean) immatures

Type of food	Percent survival[a]
Malephora crocea	90.9 a
Panonychus citri	34.4 bc
Panonychus citri and Malephora crocea	46.7 b
Eutetranychus banksi	4.5 d
Eutetranychus banksi and Malephora crocea	7.8 d
Eotetranychus sexmaculatus	28.9 c

[a] Means not having the same letter are significantly different ($P \leq 0.05$; ANOVA procedure [SAS Institute 1985]).

immatures that fed upon *P. citri* stages and females that developed on this food did not lay eggs.

No feeding was noticed on the citrus rust mite, *P. oleivora* and complete mortality of *E. mesembrinus* females occurred after 6 d when this eriophyid was the only food source provided. *E. scutalis* (*A. gossipi*) in Egypt was able to feed and reproduce on the tomato erineum mite *E. lycopersici* (Abou-Awad 1983). *E. concordis* in Brazil was reported to develop when fed on the tomato russet mite, *A. lycopersici* (Moraes & Lima 1983). The ability of immatures and adult female stages of *E. mesembrinus* to feed and develop on tetranychid mite stages was demonstrated. This suggests that *E. mesembrinus* has a role in regulating tetranychid mite species on Florida citrus.

Pollens from flowering plants in citrus groves may be a factor in survival of this phytoseiid throughout the year. The selection and evaluation of ground cover plants in Florida citrus groves should be evaluated to optimize population development of *E. mesembrinus*. Windblown pollen grains from plants outside of the orchard could also be important (Kennett et al. 1979).

Life 48: BASIC Computer Program for Calculation of Life Table Parameters

To evaluate the accuracy of this program, previously calculated (X), (Mx) and (Lx) values from published data by Birch (1948) for *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae), were used. The obtained results of this program gave a calculated r_m value of 0.761957 versus the estimated r_m value of 0.76 by Birch (1948). The program printout for this validation is presented in Fig. 7. This program

```
*                     LIFE TABLE DATA SHEET        LIFE48.LIS;2 *
*                                                               *
*   THE MITE OR INSECT NAME : SITOPHILUS ORYZAE (L.)            *
*   THE TEMPERATURE USED WAS : 29°C                             *
*                                                               *
*     X       Mx      Lx     MxLx        RML                    *
*                                                               *
*    4.50   20.00   0.87   17.400     .564206                   *
*    5.50   23.00   0.83   19.090     .288922                   *
*    6.50   15.00   0.81   12.150     .085830                   *
*    7.50   12.50   0.80   10.000     .032972                   *
*    8.50   12.50   0.79    9.875     .015197                   *
*    9.50   14.00   0.77   10.780     .007744                   *
*   10.50   12.50   0.74    9.250     .003101                   *
*   11.50   14.50   0.66    9.570     .001498                   *
*   12.50   11.00   0.59    6.490     .000474                   *
*   13.50    9.50   0.52    4.940     .000168                   *
*   14.50    2.50   0.45    1.125     .000018                   *
*   15.50    2.50   0.36    0.900     .000007                   *
*   16.50    2.50   0.29    0.725     .000003                   *
*   17.50    4.00   0.25    1.000     .000002                   *
*   18.50    1.00   0.19    0.190     .000000                   *
*                                                               *
*  THE OBSERVATION (OBS.) INTERVAL USED WAS 1 WEEK              *
*  THE DEVELOPMENTAL TIME WAS CONSIDERED AS  4  INTERVALS       *
*                                                               *
*  THE SUM OF RML                                =  1.00014     *
*  THE NET REPRODUCTIVE RATE   (Ro)              =  113.485     *
*  THE GENERATION TIME (T) IN OBS. INTERVALS     =  6.20989     *
*  THE INTRINSIC RATE OF NATURAL INCREASE (rm) =  .761957       *
*  THE FINITE RATE OF INCREASE                   =  2.14246     *
*                                                               *
*       COLUMN DEFINITIONS                                      *
*                                                               *
*  X    - Actual female age (time from egg stage)               *
*  Mx   - Female progeny per female                             *
*  Lx   - Rate of survival                                      *
*  MxLx- Female progeny per female times rate of survival       *
*  RML - MxLx times (e raised to the power of (-rm times X)) *
*     (COLUMNS Mx & Lx CONTAIN THE INPUT DATA)                  *
```

Figure 7. Validation of Life 48 program using data presented by Birch (1948).

substantially reduces the time and effort required for calculating precise life table parameters.

Log-probit Model for Developmental Time, Finite Rate of Increase, and Temperature

Samples of program printouts for developmental time and finite rate of increase are presented (Figs. 8-9). The probit of developmental time was inversely correlated with temperature while the probit of the finite rate of increase was positively correlated with temperature (Table 9). The mean R^2 was 0.9366 (SD = 0.0242, n = 32) for all data used. The mean R^2 for life table studies conducted under the same environmental conditions that included developmental time and the intrinsic rate of natural increase was 0.965 (SD = 0.0384, n = 6). A remarkable similarity of expected results was obtained when the same species was studied at two locations (Nos. 10 and 11 in Table 9) (Mahr 1978). Closely related species (Nos. 14-15 and 16-18 in Table 9) (Sheriff 1982) also had similar expected results.

The linear Log-probit model agreed with the hypothetical diagram presented by Andrewartha and Birch (1954) for the relationship between temperature and rate of development in animals. They indicated the zone of favorable temperature to be a logistic curve.

According to the Log-probit model, a good experimental design for life table parameters should contain four or more temperatures within the thermal tolerance range of the species studied under a controlled environment. Less than four values provides a poor fit to this model. One temperature should be below 20°C and another temperature below the point at which the influence of temperature changes from stimulation to inhibition so that the entire range is evaluated.

```
*PROGRAM NAME: LOG-PROBIT MODEL                                   *
*                                                                 *
*# 23 HAZAN ET AL 1973 TETRANYCHUS CINNABARINUS (HIGH HUMIDITY)   *
*                                                                 *
*                                       ----EXPECTED---           *
*                                                                 *
*TEMP     DT        1/DT       Y          Y         DT            *
* 19      19.1      .052      4.036     4.011     18.376          *
* 24      11.5      .087      3.723     3.761     12.263          *
* 30      7.8       .128      3.513     3.523     7.948           *
* 35      6         .167      3.38      3.358     5.735           *
*                                                                 *
*                                                                 *
* DAY-DEGREE MODEL                                                *
*                                                                 *
* 1/DT = -.834555E-01  +  .711117E-02  TEMP                       *
* THE DETERMINATION FACTOR R-squared =  .999341                   *
* THE THRESHOLD TEMPERATURE     =  11.7358  C                     *
*                                                                 *
*                                                                 *
* LOG-PROBIT MODEL                                                *
*                                                                 *
* PROBIT ( DT ) =  7.15441  + -1.06771  ln( TEMP )                *
* THE DETERMINATION FACTOR R-squared =  .989205                   *
*                                                                 *
*                                                                 *
* TEMP (C)   10      20      25      30      35      37           *
* EXPECTED                                                        *
*    DT     43.37   16.88   11.37   7.95    5.74    5.07          *
*                                                                 *
* Y = THE CORRESPONDING PROBIT.                                   *
```

Figure 8. Sample Log-probit program output for developmental time data.

```
*PROGRAM NAME: LOG-PROBIT MODEL                                    *
*                                                                  *
*# 29 TANIGOSHI ET AL 1981 EUSEIUS HIBISCI                          *
*                                                                  *
*                                           ----EXPECTED---        *
*TEMP      rm         e^rm        Y          Y         e^rm        *
* 18      .065       1.067       5.714      5.737      1.077       *
* 21      .158       1.171       5.981      5.96       1.164       *
* 24      .201       1.223       6.143      6.153      1.226       *
* 27      .248       1.281       6.375      6.324      1.27        *
* 29      .254       1.289       6.412      6.427      1.292       *
* 32      .273       1.314       6.543      6.57       1.318       *
* 35      .291       1.338       6.702      6.699      1.337       *
*                                                                  *
*                                                                  *
* DAY-DEGREE MODEL                                                 *
*                                                                  *
*     e^rm =  .841118  +  .150291E-01  TEMP                        *
* THE DETERMINATION FACTOR R-squared =  .90951                     *
* THE THRESHOLD TEMPERATURE     = -55.9658  C                      *
*                                                                  *
*                                                                  *
* LOG-PROBIT MODEL                                                 *
*                                                                  *
* PROBIT (e^rm) =  1.55261  +  1.44758  ln( TEMP )                 *
* THE DETERMINATION FACTOR R-squared =  .993429                    *
*                                                                  *
*                                                                  *
* EXPECTED  e^rm = 1     (rm = 0.0) AT  16  C                      *
* EXPECTED  e^rm = 1.105 (rm = 0.1) AT  18.86  C                   *
* EXPECTED  e^rm = 1.221 (rm = 0.2) AT  23.73  C                   *
* EXPECTED  e^rm = 1.35  (rm = 0.3) AT  37.62  C                   *
*                                                                  *
*                                                                  *
* TEMP (C)   10       20       25       30       35       37       *
* EXPECTED                                                         *
*   e^rm    .64      1.14     1.24     1.3      1.34     1.35      *
*                                                                  *
* Y = THE CORRESPONDING PROBIT.                                    *
```

Figure 9. Sample Log-probit program output for finite rate of increase data.

Table 9. The results of applying the Log-probit model to data collected from published literature cited in Table 1 for phytoseiid and tetranychid mites

	Regression values			Expected values at						
No.	r^2	Intercept	Slope	10°C	20°C	25°C	30°C	35°C	37°C	$r_m = 0$
				Developmental time of Phytoseiidae						
1	.904	8.256	-1.462	45.19	12.95	7.30	4.27	2.59	2.14	--
2	.964	6.974	-1.004	19.85	8.12	5.62	4.03	2.98	2.66	--
3	.962	7.664	-1.142	35.44	15.48	10.74	7.67	5.60	4.98	--
4	.892	7.118	-1.057	33.86	13.25	8.96	6.29	4.55	4.03	--
5	.933	7.160	-1.176	30.62	9.08	5.46	3.45	2.27	1.94	--
6	.971	7.271	-0.961	15.69	8.14	6.16	4.78	3.78	3.45	--
7	.906	7.703	-1.215	44.39	16.75	10.91	7.33	5.08	4.42	--
8	.909	7.270	-1.151	52.07	17.65	11.18	7.40	5.06	4.38	--
9	.913	6.470	-0.826	28.95	13.71	10.21	7.84	6.19	5.67	--
10	.872	7.741	-1.205	42.72	16.85	11.16	7.64	5.36	4.69	--
11	.944	7.714	-1.268	60.23	20.02	12.34	7.91	5.24	4.47	--

Table 9. Continued

No.	Regression values			Expected values at						
	r^2	Intercept	Slope	10°C	20°C	25°C	30°C	35°C	37°C	$r_m = 0$
12	.956	8.029	-1.415	34.35	9.49	5.33	3.12	1.90	1.57	--
13	.873	9.346	-1.557	23.30	11.25	7.58	5.14	3.52	3.03	--
14	.872	8.956	-1.473	25.72	11.70	7.82	5.29	3.63	3.14	--
15	.868	9.520	-1.603	23.88	11.64	7.81	5.25	3.56	3.06	--
16	.883	8.825	-1.437	20.91	9.46	6.35	4.32	2.99	2.59	--
17	.974	8.793	-1.556	42.04	13.90	8.10	4.84	2.97	2.46	--
18	.969	11.68	-2.320	32.75	14.18	7.76	4.07	2.10	1.62	--
19	.972	7.160	-1.018	32.02	14.01	9.91	7.24	5.42	4.87	--
20	.925	7.196	-1.015	21.30	9.55	6.81	5.01	3.78	3.40	--
21	.940	8.141	-1.326	24.06	9.13	5.84	3.85	2.60	2.24	--

Table 9. Continued

	Regression values			Expected values at						
No.	r^2	Intercept	Slope	10°C	20°C	25°C	30°C	35°C	37°C	$r_m = 0$
				Developmental time of Tetranychidae						
22	.968	7.668	-1.150	36.55	15.72	10.83	7.68	5.58	4.94	--
23	.989	7.154	-1.068	43.37	16.88	11.37	7.95	5.74	5.07	--
24	.913	9.011	-1.501	48.99	21.60	14.17	9.41	6.36	5.45	--
25	.973	6.120	-0.858	56.36	21.15	14.50	10.40	7.70	6.90	--
26	.934	6.485	-1.008	69.18	21.45	13.50	8.93	6.17	5.37	--
				Finite rate of increase of Phytoseiidae						
27	.941	3.004	0.489	0.74	1.14	1.29	1.42	1.53	1.57	15.99
28	.965	3.843	0.499	0.90	1.15	1.22	1.28	1.33	1.35	13.06
29	.993	1.553	1.448	0.64	1.14	1.24	1.30	1.34	1.35	16.00
				Finite rate of increase of Tetranychidae						
30	.976	0.977	1.607	0.56	1.18	1.31	1.39	1.43	1.44	16.00
31	.984	2.101	1.358	0.77	1.14	1.21	1.24	1.27	1.27	14.54
32	.932	3.240	0.454	0.80	1.16	1.28	1.39	1.48	1.52	15.02

The finite rate of increase studies indicated that 15°C could be considered a threshold temperature for population increase (at which $r_m = 0$ or $\exp r_m = 1$) for most species studied (Table 9). This result could form a basis for more sophisticated programs concerning biological control efficiency or injury levels for a mite species.

The Log-probit model accurately describes the relationship between selected mite species and their response to temperature as reflected by developmental time or finite rate of increase within the favorable range.

CONCLUSIONS

Euseius mesembrinus can feed and develop on pollen as well as tetranychid mites. This phytoseiid species has a high demand for nutritionally rich food because of its rapid development from egg to adult (i.e., less than five days within the range of 26 to 30°C) and relative large size of the egg compared to the female's body size. A gravid female usually has only one large egg within her body. The output/input ratio of their food has to be high in favor of the mite. A high fecundity rate would require a continuous source of food rich in protein. Animal protein when available would be easy to convert to egg production. Plant pollen, especially the starchless type, would be another protein food source requiring less expended energy.

Plant juice may provide a water source for digestion and survival but E. mesembrinus cannot depend on it as the main source of protein.

This ability to feed on plant pollen and mites at the same time allows E. mesembrinus to be population independent of population density of its tetranychid mite prey. This may be especially true in early spring when pollen is available in the field from different plant sources and tetranychid mite populations are low. As spring continues and temperature increases, pollen sources decline and tetranychid mite populations increase. E. mesembrinus should be able to suppress the tetranychid mite populations (i.e., P. citri, E. banksi, and E. sexmaculatus) if the population of this predator is not interrupted with an adverse factor such as a broad spectrum pesticide.

Obligatory predators (i.e., genus Phytoseiulus) generally have stronger body structure and better searching ability. Also, they have higher r_m values for population increase when feeding on various groups of phytophagous mites. Because phytophagous mites are not abundant throughout the year, this group of predators requires some kind of dormancy when prey become scarce. Also, population dynamics of obligatory predators fluctuate frequently as a result of their high r_m values (population density dependent dynamics). These predators are successfully used in greenhouses in Europe to control phytophagous mites, but they have to be supplied continuously as new pest mite infestations develop. Obligatory predators are highly efficient as biological control organisms but cannot survive when prey are substantially reduced or not available. This group of predatory mites seems to fit more in temperate zones on deciduous crops where changes of weather, vegetation cycles, and phytophagous mite infestations occur during specific times of the year.

The facultative group of predatory mites seems more adapted to subtropical conditions such as Florida's climate, where vegetation is available throughout the year. Environmental conditions allow various crops, including citrus, to flower during different seasons and a series of alternative food sources are thus available.

E. mesembrinus is expected to be prevalent on citrus in Florida and have the same pattern reported by Browning (1983) in South Texas. This phytoseiid was collected on different occasions in Central and South Florida suggesting its widespread distribution in these areas. E. mesembrinus appears to have a role with other indigenous predators in Florida in regulating tetranychid mites on citrus.

E. mesembrinus is adapted to Florida weather, including the recent freezes. It was collected on a citrus tree in Lake Alfred, in January, 1984 shortly after the December, 1983 freeze.

Some relationship to citrus seems to exist. It was noticed that the leaf age used in the arena affected this mite's development and subsequent population increase in culture. When water and ice plant pollen were used on a plastic arena, the culture was able to continue for more than two months. However, when old leaves were used, it was a limiting factor on culture survival. Newly hardened flush of 'Hamlin' orange was used successfully in rearing E. mesembrinus.

This phytoseiid was also collected from flowers of Spanish needle, B. pilosa, which is a common ground cover weed in Florida citrus groves. Flowering by this plant occurs virtually throughout the year in Central and South Florida. Horticultural maintenance of flowering ground cover plants in citrus groves may promote/increase the abundance of this phytoseiid as well as other pollen feeding mite predators.

The conducted studies suggest that E. mesembrinus is a potential predator of tetranychid mites on Florida citrus as a low density regulator within a temperature range of 26 to 30°C. P. citri appeared to be the most suitable prey for E. mesembrinus of the three species of tetranychid mites evaluated. The eriophyid mite, P. oleivora, was not suitable.

There are several factors that limit the potential of E. mesembrinus as a predatory mite including: the effect of high temperatures, low relative humidity, the inability to feed on either the egg stage of P. citri, or stages of the citrus rust mite, the prey and predator distribution within the tree canopy, and the necessity of alternate food sources.

The optimal temperature range of population increase for E. mesembrinus was determined to be in the range of 26 to 30°C. Temperatures over 30°C resulted in high mortality of the immature stages. However, an optimal temperature range of 30 to 35°C has been determined for some spider mites in the genus Tetranychus (Hazan et al. 1973, Tanigoshi et al. 1975b). Summer temperatures in Florida often exceed the 30°C margin, especially in the southern counties. This would eliminate any efficiency of E. mesembrinus as a tetranychid mite predator during this time of the year.

The actual effect of relative humidity was not considered in this study. Relative humidity was kept between 75 to 85% RH. It was noticed that a relative humidity lower than 70% caused high mortality in the egg stage of E. mesembrinus. The egg stage of E. mesembrinus developed in 1.5 d at 26°C compared with 5 d for P. citri eggs at the same temperature. Because of the relatively fast development of E. mesembrinus eggs, it appears that little energy is invested in the thin chorion of these eggs. The chorion usually protects the egg from water loss. Eggs of E. mesembrinus in field collected samples are usually found on the lower leaf surface. In many cases, eggs were deposited individually on webbing produced by spiders. This behavior of the females protects the eggs from exposure to direct sunlight and heat. Also, the evaporation from the lower leaf surface is greater because of the higher density of stomata.

On the other hand, P. citri has a better chance to increase at relative humidities below 70% (Munger 1963). Each P. citri egg usually has a tent of fine webbing. This tent works as a micro-incubator. The webbing reduces air movement and provides a modified environment around the egg. The silky fibers of the webbing act as a nucleus for water vapor condensation. This keeps the relative humidity around the egg in the proper range for subsequent hatching. The percentage of egg hatching of Tetranychus cinnabarinus (Boisduval) was reduced significantly for eggs separated from their surrounding webbing at different temperatures (Gerson 1979).

E. mesembrinus females were not able to feed on the egg stage of P. citri. This inability also was observed in the phytoseiids Typhlodromalus peregrinus (Muma) and Galendromus helveolus (Chant), which occur on Florida citrus. McMurtry (1982) indicated that the cheliceral structure of species in the genus Euseius is the least developed within the family Phytoseiidae. The ability to feed on the egg stage is an important factor in regulating a tetranychid mite species.

The location of the prey and the predator within the tree canopy is another factor to be considered. Infestations of P. citri tend to occur in the outer part of the citrus tree canopy. This area of the tree would provide a higher temperature than the inner shaded area. Also, most of the new flush occurs on the outer canopy. Younger leaves usually have a higher protein/carbohydrate ratio, as well as a higher water and oil (aromatic) content than older leaves. E. mesembrinus individuals were observed to occupy the inside part of the tree. Also, new leaves characterized with a high odor were not suitable for rearing E. mesembrinus. The behavior of occupying the inner tree canopy was reported to be common in the family Phytoseiidae (McMurtry et al. 1970).

The necessity of alternate food sources in citrus groves is an important factor. A source of pollen as an alternate food for E. mesembrinus may not be available in monocultural cropping systems that utilize weed control programs. E. mesembrinus would not be able to survive in case of tetranychid mite scarcity unless this species has a high ability of dispersal from one area to another.

Peak activity of E. mesembrinus in Florida citrus is expected to be mainly in the spring and fall seasons in citrus groves with flowering ground cover plants available. Enhancing the role of E. mesembrinus in citrus groves by allowing alternate food sources, rather than rearing it for release would be the better choice in an integrated pest management program.

Based on this research, the following objectives should be considered in the future. The seasonal abundance and distribution of E. mesembrinus on Florida citrus in relation to the presence or absence of different spider mites needs to be determined. The potential of E. mesembrinus to feed and successfully develop on other groups of arthropods including whitefly larvae, thrips, scale insect crawlers and eggs, and mites in the families Tenuipalpidae, Tarsonemidae, and Tydeidae should be determined.

The ability of E. mesembrinus to feed and increase on different types of pollen that occur naturally within and around Florida citrus groves needs to be evaluated. Also, the effect of different horticultural maintenance procedures on the balance between tetranychid mite populations and this phytoseiid mite needs to be addressed. This includes the comparative toxicity and residual effects of all recommended pesticides on E. mesembrinus. The effect of different relative humidity regimes on the survival of E. mesembrinus stages was not determined in this study. Also, the ability of E. mesembrinus to regulate different population densities of tetranychid mites, including functional and numerical responses of the predatory mite, needs to be determined.

The interaction, replacement, and competition between E. mesembrinus and other phytoseiid mites that occur on Florida citrus need to be identified. The ultimate goal would be to design a pest management program for Florida citrus utilizing all available tools including the use of predaceous mites and insects to regulate the citrus rust mite, the Texas citrus mite, and the citrus red mite without environmental interference.

Although the Life 48 BASIC computer program is a simple process to use on microcomputers, the run time is relatively long. Rewriting this program in a faster programming language such as Pascal may be necessary. The method pointed out to me by Dr. Jon C. Allen using Newton's method for equation solving may be appropriate for increasing speed.

The method presented by Birch (1948) which was followed here did not indicate any source of variance for the obtained values. This may have been ignored because of the tedious mathematical procedures required for obtaining one value for each parameter. With the availability of computers and programs to handle these procedures, a better design for life table studies can be considered by dividing the data into replicates. We can then obtain a mean and variance for each of the r_m, R_o, and T values for better statistical comparisons.

The Log-probit model is appropriate to fit the relationship between temperature as a stimulus and developmental time or finite rate of increase of mites within the favorable range. This model also establishes a population increase temperature threshold (PITT). Although the day-degree (DD) method seems to be easy to understand and apply, it ignores the effect of low and high temperatures. Calculating the temperatures over the PITT for an arthropod population increase using either the Log-probit model or DD method would reflect better forecasting for population development. Below this temperature, individual development may occur but the population may decline because of the negative value of r_m.

SUMMARY

The primary objective of this study was to determine the biology and life tables of Euseius mesembrinus. The results are summarized as follows:

1. Scanning electron micrographs of E. mesembrinus validated the species description from previous studies.

2. The developmental times of immature stages of E. mesembrinus fed pollen of M. crocea at 18, 22, 26, and 30°C were 11.50, 7.47, 4.54, and 4.4 days, respectively. The optimum temperature for this phytoseiid to develop and increase on ice plant pollen was 26 to 30°C.

3. Life table parameters were constructed for E. mesembrinus where immatures developed on ice plant pollen and adult females were then provided one prey species or ice plant pollen at 26°C and 70% relative humidity. Each prey species was allowed to increase on a modified citrus leaf arena before introducing newly mature adult females of E. mesembrinus. The r_m values for E. mesembrinus were calculated as 0.199, 0.191, 0.166, and 0.244 when fed P. citri, E. banksi, E. sexmaculatus, and M. crocea pollen, respectively.

4. The citrus rust mite, P. oleivora, was not a suitable prey.

5. Life 48, a BASIC computer program, was developed to carry out the calculations of life table parameters using age-specific distribution data. This program was validated using the original data presented by Birch (1948).

6. Log-probit BASIC computer program was developed to evaluate the goodness-of-fit of the relationship between temperature and both developmental time and finite rate of increase for mites in the families, Phytoseiidae and Tetranychidae.

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APPENDIX A

LISTING OF LIFE 48 BASIC COMPUTER PROGRAM

```
100 REM PROGRAM LIFE 48                         JULY 1985
110 REM M. M. ABOU-SETTA, R. W. SORRELL, AND C. C. CHILDERS
120 REM   THIS PROGRAM CAN RUN ON BOTH A DEC VAX MINICOMPUTER
121 REM     AND ON THE IBM PC MICROCOMPUTER AND COMPATIBLES IF
122 REM     APPROPRIATE CHANGES ARE MADE AS DESCRIBED ON LINES
123 REM      930 THROUGH 950 150 REM  DEFINE OUTPUT FILE
160 REM  INPUT INITIAL PARAMETERS 170 ON ERROR GOTO 1220
180  INPUT "   ENTER MITE OR INSECT NAME  ";TITLE$
190  INPUT "   ENTER THE TEMPERATURE USED (C) ";TEMP$
200  INPUT "   ENTER THE NUMBER OF OBSERVATIONS  ";N
210  INPUT "   ENTER THE INITIAL NUMBER OF FEMALES ";NF
220  PRINT "   ENTER THE TIME INTERVAL BETWEEN OBSERVATIONS ";
221  INPUT TIMINT$
230  PRINT "   ENTER THE DEVELOPMENT TIME FROM EGG TO ADULT ";
231  PRINT "FEMALE "
240  INPUT "      AS THE NUMBER OF OBSERVATION INTERVALS ";DT
250  PRINT "   ENTER THE FRACTION OF EGGS LAID REACHING ";
251  INPUT "MATURITY ";PERM
260  INPUT "   ENTER THE SEX RATIO AS FEMALES PER TOTAL ";SR
270 DIM X(N), M(N), M1(N), MX(N), L(N), LX(N)
271 DIM MXLX(N), XML(N), RML(N)
280 PRINT
290 PRINT "   ENTER THE NUMBER OF EGGS LAID FOR EACH INTERVAL";
300 PRINT " (M) FOR ";N;" INTERVALS"
310 PRINT
320  FOR C = 1 TO N
330   PRINT "  ";C;"   ";
340   INPUT M(C)
350  NEXT C
360 PRINT
370 PRINT "   ENTER THE NO. OF SURVIVING FEMALES FOR EACH "
375 PRINT "     INTERVAL (L) FROM 1 TO ";N;" UNITS ";
376 PRINT "(OBSERVATION "
380 PRINT "     INTERVALS) OF ADULT AGE"
390  FOR C =1 TO N
400   PRINT "  ";C;"   ";
410   INPUT L(C)
420   IF L(C) > 0 AND L(C) <= NF THEN 450
430   PRINT " ERROR - NUMBER MUST BE GREATER THAN 0 AND LESS ";
431   PRINT "THAN ";NF
440   GOTO 400
450  NEXT C
460 PRINT
470 REM  CALCULATING THE DAILY AND LIFE TABLE VALUES
```

```
480 FOR C = 1 TO N
490  X(C) = C + DT - .5
500  M1(C)= M(C) / L(C)
510  LX(C) = L(C) * PERM / NF
520  MX(C) = M1(C) * SR
530  MXLX(C)= MX(C)  * LX(C)
540  XML(C)= MXLX(C) * X(C)
550  EXML =  EXML + XML(C)
560  RO  = RO + MXLX(C)
570 NEXT C
580 REM  CALCULATING THE APPROXIMATE VALUE OF RM
590  RM = LOG( RO ) / (EXML / RO)
600  FOR C = 1 TO N
610   RML(C) = MXLX(C) / EXP( X(C) * RM )
620   ERML = ERML + RML(C)
630  NEXT C
640 REM  FINDING THE ACCURATE (RM) USING THE APPROXIMATE VALUE
645 REM     AS A GUIDE
650 IF ERML<=1.0005 AND ERML=>.9995 THEN 800
651 IF ERML<.9995 THEN 730
660  ERML = 0
670  RM = RM + .0001
680 FOR C = 1 TO N
690  RML(C) = MXLX(C) / EXP( X(C) * RM )
700  ERML = ERML + RML(C)
710 NEXT C
720 IF ERML > 1.0005 THEN 660 ELSE 800
730  ERML = 0
740  RM = RM - .0001
750 FOR C = 1 TO N
760  RML(C) = MXLX(C) / EXP( RM * X(C) )
770  ERML = ERML + RML(C)
780 NEXT C
790 IF ERML < .9995 THEN 730
800  T = LOG( RO ) / RM
810 PRINT " ENTER NAME OF FILE IN WHICH RESULTS WILL BE ";
811 INPUT "PLACED ";FILE$
820 OPEN FILE$ FOR OUTPUT AS #1
830 PRINT #1," "
840 PRINT #1,"                  LIFE TABLE DATA SHEET";
841 PRINT #1,"   ";FILE$
850 PRINT #1," "
860 PRINT #1,"   THE MITE OR INSECT NAME : ";TITLE$
870 PRINT #1,"   THE TEMPERATURE USED WAS : ";TEMP$;" °C"
880 PRINT #1," "
890 PRINT #1,"    M      L       X      Mx     Lx     ";
891 PRINT #1,"MxLx       RML"
900 PRINT #1," "
910 F1$ =  "   ###    ###    ##.##  ##.##   #.##   ##.###    ";
911 F2$ =  " .######"
912 F$  = F1$ + F2$
920 FOR C = 1 TO N
930 REM FOR IBM COMPATIBILITY, A COMMA MUST BE PLACED AFTER
931 REM THE #1 IN LINE 960 ( PRINT #1, USING ).
932 REM FOR THE VAX, A COMMA MUST NOT BE PRESENT
933 REM (PRINT #1 USING)
```

```
960 PRINT #1 USING F$;M(C);L(C);X(C);MX(C);LX(C);MXLX(C);RML(C)
970 NEXT C
980 PRINT #1," "
990 PRINT #1,"  OBSERVATION (OBS.) INTERVAL USED WAS ";TIMINT$
1000 PRINT #1,"  DEVELOPMENTAL TIME USED WAS ";DT;" INTERVALS"
1010 PRINT #1,"  SEX RATIO WAS (FEMALES/TOTAL): ";SR
1020 PRINT #1,"  FRACTION OF EGGS REACHING MATURITY :  ";PERM
1030 PRINT #1," "
1040 PRINT #1,"  SUM OF RML                              = "
1041 PRINT #1,ERML
1050 PRINT #1,"  NET REPRODUCTIVE RATE   (Ro)            = ";RO
1060 PRINT #1,"  GENERATION TIME (T) IN OBS. INTERVALS   = ";T
1070 PRINT #1,"  INTRINSIC RATE OF NATURAL INCREASE (rm) = ";RM
1080 PRINT #1,"  FINITE RATE OF INCREASE                 = ";
1081 PRINT #1,EXP(RM)
1090 PRINT #1," "
1100 PRINT #1,"            COLUMN DEFINITIONS"
1110 PRINT #1," "
1120 PRINT #1,"  M    - Total progeny at each interval for all";
1121 PRINT #1," females"
1130 PRINT #1,"  L    - Number of females alive  "
1140 PRINT #1,"  X    - Actual female age (time from egg stage)"
1150 PRINT #1,"  Mx   - Female progeny per female"
1160 PRINT #1,"  Lx   - Rate of survival"
1170 PRINT #1,"  MxLx- Female progeny / female times rate of";
1171 PRINT #1," survival"
1180 PRINT #1,"  RML - MxLx times (e raised to the power of ";
1181 PRINT #1,"(-rm times X))"
1190 PRINT #1,"      (COLUMNS M & L CONTAINS THE INPUT DATA) "
1200 CLOSE #1
1210 GOTO 1340
1220 REM ERROR HANDLING ROUTINE
1230 IF ERL > 470 THEN 1280
1240  PRINT " DATA ERROR - PLEASE CHECK DATA AND RE-ENTER"
1250  IF ERL = 240 THEN RESUME 230
1260  IF ERL = 410 THEN RESUME 400
1270  RESUME
1280 IF ERL <> 820 THEN 1310
1290  PRINT " ERROR OPENING OUTPUT FILE - TRY AGAIN"
1300  RESUME 810
1310 PRINT " ERROR IN PROGRAM"
1320  PRINT " ERROR #";ERR;" OCCURRED AT LINE ";ERL
1330  RESUME 1340
1340 END
```

APPENDIX B

LISTING OF LOG-PROBIT MODEL BASIC COMPUTER PROGRAM

```
100 REM   PROGRAM LOG-PROBIT MODEL  V 1.0
110 REM   MOHAMED M. ABOU-SETTA, ROBERT W. SORRELL, CARL C. CHILDERS
120 ININC = .001
130 REM PERCENT TO PROBIT TABLE
140  DIM PERCTB(17), PROBITB(17)
150  DATA  .01,1.2810,    .1,1.9098,  1,2.6737,  5,3.3551, 10,3.7184
160  DATA   20,4.1584,    30,4.4756, 40,4.7467, 50,5.0,    60,5.2533
170  DATA   70,5.5244,    80,5.8416, 90,6.2816, 95,6.6449, 99,7.3263
180  DATA 99.9,8.0902, 99.99,8.7190
190  FOR I = 1 TO 17
200   READ PERCTB(I),PROBITB(I)
210  NEXT I
220 ON ERROR GOTO 2360
230 PRINT "  ENTER TITLE INFORMATION : "
240 INPUT TITLE$
250 PRINT
260 PRINT "   REACTION NATURE MAY BE:"
270 PRINT "    DT  -  DEVELOPMENTAL TIME"
280 PRINT "    rm  -  INTRINSIC RATE OF INCREASE"
290 INPUT "   ENTER  DT OR rm ";RNATURE$
300  RNATURE$=LEFT$(RNATURE$,2)
310  IF RNATURE$="dt" THEN RNATURE$="DT"
320  IF RNATURE$="RM" THEN RNATURE$="rm"
330  IF RNATURE$<>"DT" AND RNATURE$<>"rm" THEN 290
340  IF RNATURE$="DT" THEN R$="1/DT" ELSE R$="e^rm"
350 PRINT
360 INPUT "   ENTER THE NUMBER OF REPLICATIONS (>= 3) :";N
370   IF N=INT(N) AND N>= 3THEN 400
380   PRINT " NUMBER MUST BE AN INTEGER AND GREATER THEN 3"
390   GO TO 360
400  L = N + 6
410  DIM STIM(L), REACT(L), TREACT(L), LNSTIM(L), RCTPRBT(L)
420  DIM EPROBY(L), EREACT(L), ETEMP(4)
430 PRINT "   ENTER ";N;" PAIRS OF VALUES, ONE VALUE PER LINE"
440  FOR C = 1 TO N
450   PRINT
460   PRINT " STIMULUS (TEMPERATURE) ";C;" :";
470   INPUT STIM(C)
480   PRINT " REACTION           (";RNATURE$;") ";C;" :";
490   INPUT REACT(C)
500   IF RNATURE$ ="rm" THEN 560
510   REM REACTION NATURE IS DT
520    TREACT(C)=(1/REACT(C))
530    IF REACT(C) >= MX THEN MX =REACT(C)
540    IF MX < 20 THEN MX = 20
```

```
550     GOTO 590
560    REM REACTION NATURE IS rm
570     TREACT(C)=EXP(REACT(C))
580     IF TREACT(C)>= MX THEN MX=TREACT(C)
590   NEXT C
600   PRINT
610   PRINT "  WORKING  ";
620  IF MX=>5 THEN OPT=INT(MX*.1)*10+10 ELSE OPT=(INT(MX*10)+1)*.1
630  D = OPT * .1
640  FOR C = 1 TO N
650   TT  = TT + STIM(C)
660   S1  = S1 + TREACT(C)
670   TS  = TS + STIM(C)^2
680   S2  = S2 + TREACT(C)^2
690   SX = SX+ TREACT(C) * STIM(C)
700   REM     TRANSFORMING THE TEMPERATURE TO BASE e LOG (ln)
710    LNSTIM(C) = LOG(STIM(C))
720    X1    = X1 + LNSTIM(C)
730    X2    = X2 + LNSTIM(C)^2
740  NEXT C
750   ALINEAR   = (TS* S1  - SX*TT)/(N*TS - TT^2)
760   BLINEAR   = (N * SX - S1 *TT)/(N*TS - TT^2)
770   RLIN2 = (SX - S1*TT/N)^2 / ((S2-S1^2/N) * (TS-TT^2/N))
780   T1TH = -ALINEAR / BLINEAR
790   Y1  = 0
800   Y2  = 0
810   YX  = 0
820  FOR C = 1 TO N
830  REM     TRANSFORMING THE REACTION TO A PROBIT
840  IF RNATURE$="rm" THEN M=(TREACT(C)/OPT)*100 ELSE M=(REACT(C)/OPT)*100
850  GOSUB 2090
860  RCTPRBT(C) = CLCPR
870   Y1 = Y1  + RCTPRBT(C)
880   Y2 = Y2  + RCTPRBT(C)^2
890   YX= YX + LNSTIM(C) * RCTPRBT(C)
900  NEXT C
910  RPRB2 = (YX - X1*Y1/N)^2 / ((Y2 - Y1^2/N)*(X2 - X1^2/N))
920 IF SOS = 100 THEN 1020
930  IF RPRB2 <= G THEN 990
940 REM R SQUARE STILL INCREASING
950   G = RPRB2
960   OPT = OPT + D
970   GO TO 790
980 REM R SQUARE DECREASED, USE PREVIOUS MAXIMUM
990   OPT = OPT - D
1000   SOS  = 100
1010   GO TO 790
1020  ETEMP(1) = INT( 100  /OPT *100+.5)*.01
1030  ETEMP(2) = INT( 110.5/OPT *100+.5)*.01
1040  ETEMP(3) = INT( 122.1/OPT *100+.5)*.01
1050  ETEMP(4) = INT( 135  /OPT *100+.5)*.01
1060  APROBIT = (X2*Y1 - YX*X1)/(N*X2 - X1^2)
1070  BPROBIT = (N*YX - Y1*X1)/(N*X2 - X1^2)
1080  FOR Z = 1 TO 4
1090   M = ETEMP(Z)
1100   GOSUB 2090
```

```
1110   ETEMP(Z) = INT( EXP((CLCPR - APROBIT)/BPROBIT) *100+.5)*.01
1120  NEXT Z
1130    STIM(N+1)=10
1140    STIM(N+2)=20
1150    STIM(N+3)=25
1160    STIM(N+4)=30
1170    STIM(N+5)=35
1180    STIM(N+6)=37
1190  REM  CALCULATING THE EXPECTED REACTION  VALUES
1200  FOR C = 1 TO L
1210   PRINT "*";
1220   EPROBY(C)= APROBIT + BPROBIT * (LOG(STIM(C)))
1230   FOR I = 1 TO 16
1240    IF EPROBY(C) < PROBITB(I) OR EPROBY(C) >= PROBITB(I+1) THEN 1280
1250    ISUM = PERCTB(I)
1260    BEGN = PROBITB(I)
1270    GOTO 1340
1280   NEXT I
1290   REM UPPER LIMITS
1300    IF EPROBY(C) = 8.7190 THEN ISUM = 99.99
1310    IF EPROBY(C) > 8.7190 THEN ISUM = 100
1320    IF EPROBY(C) < 1.2810 THEN ISUM = 0
1330   GOTO 1420
1340   REM INTEGRATE BY TRAPEZOIDAL RULE
1350    P1 = .3989422 * EXP(-(BEGN - 5)^2 /2) * 100
1360   FOR CLCPR = BEGN TO EPROBY(C)-ININC STEP ININC
1370    IF BEGN >= EPROBY(C) THEN 1420
1380    P2 = .3989422 * EXP(-(CLCPR+ININC - 5)^2 /2) * 100
1390    ISUM = ISUM + (P1 + P2)/ 2 * ININC
1400    P1 = P2
1410   NEXT CLCPR
1420   EREACT(C) =  ISUM  * OPT * .01
1430  NEXT C
1440  PRINT CHR$(7)
1450  PRINT
1460  INPUT " ENTER FILE NAME FOR OUTPUT : ";FILE$
1470  OPEN FILE$ FOR OUTPUT AS #1
1480  PRINT #1,
1490  PRINT #1,"   PROGRAM NAME: LOGPROBIT MODEL"
1500  PRINT #1,
1510  PRINT #1,"   ";TITLE$
1520  PRINT #1,
1530  PRINT #1,"                                          ----EXPECTED---"
1540  IF RNATURE$ = "DT"  THEN 1570
1550  PRINT #1,"   TEMP     rm        e^rm       Y          Y        e^rm"
1560  GO TO 1580
1570  PRINT #1,"   TEMP     DT        1/DT       Y          Y         DT"
1580  FOR C = 1 TO N
1590  PRINT #1, TAB(3) ;INT(STIM(C)   *10  +.5) *.1;
1600  PRINT #1, TAB(11);INT(REACT(C)  *1000+.5) *.001;
1610  PRINT #1, TAB(21);INT(TREACT(C) *1000+.5) *.001;
1620  PRINT #1, TAB(31);INT(RCTPRBT(C)*1000+.5) *.001;
1630  PRINT #1, TAB(41);INT(EPROBY(C) *1000+.5) *.001;
1640  PRINT #1, TAB(51);INT(EREACT(C) *1000+.5) *.001
1650  NEXT C
1660  PRINT #1,
1670  PRINT #1,
1680  PRINT #1,"  DAY-DEGREE MODEL"
1690  PRINT #1,
1700  PRINT #1,"          ";R$;" = ";ALINEAR;" + ";BLINEAR;" TEMP"
1710  PRINT #1,"   THE DETERMINATION FACTOR R-squared = ";RLIN2
1720  PRINT #1,"   THE THRESHOLD TEMPERATURE        = ";T1TH;" C "
1730  PRINT #1,
1740  PRINT #1,
1750  PRINT #1,"  LOG-PROBIT MODEL"
1760  IF RNATURE$="DT" THEN R$=" DT "
1770  PRINT #1,
1780  PRINT #1,"   PROBIT (";R$;") = ";APROBIT;" + ";BPROBIT;" ln( TEMP )"
1790  PRINT #1,"   THE DETERMINATION FACTOR R-squared = ";RPRB2
1800  PRINT #1,
1810  PRINT #1,
1820  IF RNATURE$ = "rm" THEN 1840
1830  GO TO 1930
1840  FOR I = 1 TO 4
1850  ETEMP(I) = INT(ETEMP(I) * 100 + .5) * .01
1860  NEXT I
1870  PRINT #1," EXPECTED  e^rm = 1     (rm = 0.0) AT ";ETEMP(1) ;" C"
1880  PRINT #1," EXPECTED  e^rm = 1.105 (rm = 0.1) AT ";ETEMP(2) ;" C"
1890  PRINT #1," EXPECTED  e^rm = 1.221 (rm = 0.2) AT ";ETEMP(3) ;" C"
1900  PRINT #1," EXPECTED  e^rm = 1.35  (rm = 0.3) AT ";ETEMP(4) ;" C"
1910  PRINT #1,
1920  PRINT #1,
1930  PRINT #1,"  TEMP (C)     10        20        25        30        35  ";
1940  PRINT #1,"     37"
1950  PRINT #1,"  EXPECTED"
1960  print #1,"   ";R$;"  ";
1970  FOR I = 1 TO 6
1980   PRINT #1, TAB(3+I*10);INT(EREACT(N+I)*100 +.5) * .01;
1990  NEXT I
2000  PRINT #1,
2010  PRINT #1,
2020  PRINT #1,"  Y = THE CORRESPONDANCE PROBIT."
2030  P1$ = "    ONE VALUE WAS TOO "
2040  P2$ = " WAS USED INSTEAD"
2050  IF LOW=1  THEN PRINT #1,P1$; "LOW,    .01%"; P2$
2060  IF HIGH=1 THEN PRINT #1,P1$; "HIGH, 99.99%"; P2$
2070 CLOSE #1
2080 GOTO 2460
2090 REM  INTEGRATION SUBROUTINE
2100 PRINT "*";
2110  FOR I = 1 TO 16
2120   IF M < PERCTB(I) OR M >= PERCTB(I+1) THEN 2160
2130   ISUM = PERCTB(I)
2140   BEGN = PROBITB(I)
2150   GOTO 2270
2160  NEXT I
2170  REM UPPER LIMITS
2180  IF M < .01 THEN 2230
2190  CLCPR = 8.7190
2200  M = 99.99
2210  HIGH = 1
2220   GOTO 2350
```

```
2230  CLCPR = 1.2810
2240  M = .01
2250  LOW = 1
2260   GOTO 2350
2270  REM INTEGRATE BY TRAPEZOIDAL RULE UNTIL PERCENT VALUE IS REACHED
2280   P1 = .3989422 * EXP(-(BEGN - 5)^2 * .5) * 100
2290   FOR CLCPR = BEGN TO 10-ININC STEP ININC
2300    IF ISUM >= M THEN 2350
2310    P2 = .3989422 * EXP(-(CLCPR + ININC - 5)^2 * .5) * 100
2320    ISUM = ISUM + (P1 + P2) * .5 * ININC
2330    P1 = P2
2340   NEXT CLCPR
2350   RETURN
2360  REM  ERROR TRAPS
2370   IF ERL=360 OR ERL=470 OR ERL=490 THEN 2420
2380   IF ERL=1470 THEN 2440
2390   REM OTHER ERRORS
2400    PRINT "** ERROR # ";ERR;"  OCCURRED AT LINE ";ERL;" **"
2410    RESUME 2460
2420   PRINT " INVALID ENTRY - TRY AGAIN"
2430    RESUME
2440   PRINT " INVALID FILE NAME - TRY AGAIN"
2450    RESUME 1460
2460   END
```

APPENDIX C

COMPUTER PRINTOUTS OF *Euseius mesembrinus* LIFE TABLES AT DIFFERENT TEMPERATURES FEEDING ON ICE PLANT POLLEN

```
LIFE TABLE DATA SHEET       LIFE48.LIS

THE MITE OR INSECT NAME : EUSEIUS MESEMBRINUS (DEAN)
THE TEMPERATURE USED WAS : 22°C

 M       L       X      Mx      Lx      MxLx        RML

 0      20     7.97    0.00    1.00    0.000     .000000
 4      20     8.97    0.14    1.00    0.135     .036329
21      20     9.97    0.71    1.00    0.709     .164764
21      20    10.97    0.71    1.00    0.709     .142334
31      20    11.97    1.05    1.00    1.046     .181508
19      20    12.97    0.64    1.00    0.641     .096103
21      20    13.97    0.71    1.00    0.709     .091759
 9      20    14.97    0.30    1.00    0.304     .033972
21      20    15.97    0.71    1.00    0.709     .068476
12      20    16.97    0.41    1.00    0.405     .033802
13      20    17.97    0.44    1.00    0.439     .031634
 9      20    18.97    0.30    1.00    0.304     .018919
 9      20    19.97    0.30    1.00    0.304     .016344
12      20    20.97    0.41    1.00    0.405     .018825
13      20    21.97    0.44    1.00    0.439     .017617
13      20    22.97    0.44    1.00    0.439     .015219
16      17    23.97    0.64    0.85    0.540     .016181
 8      15    24.97    0.36    0.75    0.270     .006989
 5      10    25.97    0.34    0.50    0.169     .003774
 3       7    26.97    0.29    0.35    0.101     .001956
 3       7    27.97    0.29    0.35    0.101     .001690
 1       6    28.97    0.11    0.30    0.034     .000487
 0       6    29.97    0.00    0.30    0.000     .000000
 1       6    30.97    0.11    0.30    0.034     .000363
 1       5    31.97    0.14    0.25    0.034     .000314
 1       4    32.97    0.17    0.20    0.034     .000271

THE OBSERVATION (OBS.) INTERVAL USED WAS 1 DAY
THE DEVELOPMENTAL TIME WAS CONSIDERED AS  7.47   INTERVALS
THE SEX RATIO WAS (FEMALES/TOTAL):  .675
THE FRACTION OF EGGS REACHING MATURITY :   1
THE SUM OF RML                                 =  .999629
THE NET REPRODUCTIVE RATE   (Ro)               =  9.01125
THE GENERATION TIME (T) IN OBS. INTERVALS      =  15.0233
THE INTRINSIC RATE OF NATURAL INCREASE (rm)    =  .146338
THE FINITE RATE OF INCREASE                  =  1.15759

       COLUMN DEFINITIONS

M    - Total progeny at each interval for all females
L    - Number of females alive
X    - Actual female age (time from egg stage)
Mx   - Female progeny per female
Lx   - Rate of survival
MxLx- Female progeny per female times rate of survival
RML - MxLx times (e raised to the power of (-rm times x))
        (COLUMNS M & L CONTAIN THE INPUT DATA)
```

```
          LIFE TABLE DATA SHEET       LIFE48.LIS

THE MITE OR INSECT NAME : EUSEIUS MESEMBRINUS (DEAN)
THE TEMPERATURE USED WAS : 26°C

 M      L       X       Mx     Lx     MxLx       RML

 0     20     5.04    0.00   1.00    0.000     .000000
39     20     6.04    0.98   1.00    0.975     .215632
48     20     7.04    1.20   1.00    1.200     .206727
45     20     8.04    1.13   1.00    1.125     .150965
42     20     9.04    1.05   1.00    1.050     .109755
33     20    10.04    0.82   1.00    0.825     .067173
49     20    11.04    1.23   1.00    1.225     .077694
42     20    12.04    1.05   1.00    1.050     .051874
36     20    13.04    0.90   1.00    0.900     .034634
29     20    14.04    0.73   1.00    0.725     .021733
25     20    15.04    0.63   1.00    0.625     .014594
29     20    16.04    0.73   1.00    0.725     .013186
26     20    17.04    0.65   1.00    0.650     .009209
25     20    18.04    0.63   1.00    0.625     .006897
26     20    19.04    0.65   1.00    0.650     .005588
25     20    20.04    0.63   1.00    0.625     .004185
27     20    21.04    0.68   1.00    0.675     .003521
23     20    22.04    0.57   1.00    0.575     .002336
17     20    23.04    0.43   1.00    0.425     .001345
15     19    24.04    0.39   0.95    0.375     .000924
15     19    25.04    0.39   0.95    0.375     .000720
13     18    26.04    0.36   0.90    0.325     .000486
11     16    27.04    0.34   0.80    0.275     .000320
 9     14    28.04    0.32   0.70    0.225     .000204
 7     11    29.04    0.32   0.55    0.175     .000124
 4      6    30.04    0.33   0.30    0.100     .000055
 2      3    31.04    0.33   0.15    0.050     .000021

THE OBSERVATION (OBS.) INTERVAL USED WAS 1 DAY
THE DEVELOPMENTAL TIME WAS CONSIDERED AS  4.54   INTERVALS
THE SEX RATIO WAS (FEMALES/TOTAL):  .5
THE FRACTION OF EGGS REACHING MATURITY :   1
THE SUM OF RML                              =  .999904
THE NET REPRODUCTIVE RATE   (Ro)            =  16.55
THE GENERATION TIME (T) IN OBS. INTERVALS   =  11.234
THE INTRINSIC RATE OF NATURAL INCREASE (rm) =  .249812
THE FINITE RATE OF INCREASE                 =  1.28378

          COLUMN DEFINITIONS

M    - Total progeny at each interval for all females
L    - Number of females alive
X    - Actual female age (time from egg stage)
Mx   - Female progeny per female
Lx   - Rate of survival
MxLx- Female progeny per female times rate of survival
RML - MxLx times (e raised to the power of (-rm times x))
       (COLUMNS M & L CONTAIN THE INPUT DATA)
```

```
          LIFE TABLE DATA SHEET        LIFE48.LIS;1

THE MITE OR INSECT NAME : EUSEIUS MESEMBRINUS (DEAN)
    THE TEMPERATURE USED WAS : 30°C

 M      L        X       Mx      Lx      MxLx        RML

 4     20      4.90    0.12    1.00     0.122     .036599
46     20      5.90    1.40    1.00     1.403     .329197
34     20      6.90    1.04    1.00     1.037     .190311
33     20      7.90    1.01    1.00     1.007     .144473
26     20      8.90    0.79    1.00     0.793     .089030
27     20      9.90    0.82    1.00     0.824     .072312
23     20     10.90    0.70    1.00     0.701     .048180
16     20     11.90    0.49    1.00     0.488     .026215
15     20     12.90    0.46    1.00     0.458     .019222
15     19     13.90    0.48    0.95     0.458     .015035
16     18     14.90    0.54    0.90     0.488     .012543
 7     18     15.90    0.24    0.90     0.213     .004292
 9     16     16.90    0.34    0.80     0.275     .004316
11     16     17.90    0.42    0.80     0.336     .004126
 9     15     18.90    0.37    0.75     0.275     .002640
 5     15     19.90    0.20    0.75     0.153     .001147
 2     13     20.90    0.09    0.65     0.061     .000359
 2     13     21.90    0.09    0.65     0.061     .000281

THE OBSERVATION (OBS.) INTERVAL USED WAS 1 DAY
THE DEVELOPMENTAL TIME WAS CONSIDERED AS  4.4  INTERVALS
THE SEX RATIO WAS (FEMALES/TOTAL):  .61
THE FRACTION OF EGGS REACHING MATURITY :   1

THE SUM OF RML                                =  1.00028
THE NET REPRODUCTIVE RATE   (Ro)              =  9.15
THE GENERATION TIME (T) IN OBS. INTERVALS     =  9.00947
THE INTRINSIC RATE OF NATURAL INCREASE (rm) =  .245714
THE FINITE RATE OF INCREASE                   =  1.27853

       COLUMN DEFINITIONS

M    - Total progeny at each interval for all females
L    - Number of females alive
X    - Actual female age (time from egg stage)
Mx   - Female progeny per female
Lx   - Rate of survival
MxLx- Female progeny per female times rate of survival
RML - MxLx times (e raised to the power of (-rm times X))
        (COLUMNS M & L CONTAIN THE INPUT DATA)
```

APPENDIX D

COMPUTER PRINT OUTS OF APPLYING LOG-PROBIT MODEL TO *Euseius mesembrinus* STAGES DEVELOPMENTAL TIME

```
PROGRAM NAME: LOG-PROBIT MODEL

EUSIEUS MESEMBRINUS (EGG)

                                                   ----EXPECTED---
TEMP       DT         1/DT        Y          Y          DT
 18        3.64       .275        3.725      3.71       3.541
 22        2.44       .41         3.508      3.503      2.415
 26        1.48       .676        3.263      3.331      1.707
 30        1.38       .725        3.23       3.183      1.245

DAY-DEGREE MODEL

     1/DT = -.448128  +  .403894E-01  TEMP
THE DETERMINATION FACTOR R-squared =  .942942
THE THRESHOLD TEMPERATURE     =  11.0952  C


LOG-PROBIT MODEL

PROBIT ( DT ) =  6.68985  + -1.03107  ln( TEMP )
THE DETERMINATION FACTOR R-squared =  .956246


TEMP (C)   10      20      25      30      35      37
EXPECTED
  DT      8.88    2.91    1.86    1.24    .87     .76

Y = THE CORRESPONDING PROBIT.
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```
PROGRAM NAME: LOG-PROBIT MODEL

EUSEIUS MESEMBRINUS (LARVAE)

                                                ----EXPECTED---
TEMP     DT        1/DT        Y           Y          DT
 18      2.49      .402        3.564       3.505      2.222
 22      1.28      .781        3.236       3.316      1.52
 26      1         1           3.124       3.159      1.082
 30      .91       1.099       3.083       3.025      .796

DAY-DEGREE MODEL

     1/DT = -.565941  +  .577658E-01  TEMP
THE DETERMINATION FACTOR R-squared =  .930987
THE THRESHOLD TEMPERATURE      =  9.79717  C


LOG-PROBIT MODEL

PROBIT ( DT ) =  6.21997  + -.939361  ln( TEMP )
          THE DETERMINATION FACTOR R-squared =  .897508


TEMP (C)   10      20      25      30      35      37
EXPECTED
   DT     5.7     1.83    1.17    .8      .56     .49

Y = THE CORRESPONDING PROBIT.
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PROGRAM NAME: LOG-PROBIT MODEL

EUSEIUS MESEMBRINUS (PROTONYMPH)

                                       ----EXPECTED---
TEMP     DT        1/DT       Y          Y         DT
 18      2.71      .369      3.662      3.632     2.57
 22      1.7       .588      3.417      3.431     1.75
 26      1.05      .952      3.189      3.264     1.235
 30      1.03      .971      3.18       3.12      .901

DAY-DEGREE MODEL

     1/DT = -.581732  +  .542439E-01  TEMP
THE DETERMINATION FACTOR R-squared =  .91415
THE THRESHOLD TEMPERATURE     =  10.7244  C

LOG-PROBIT MODEL

PROBIT ( DT ) =  6.53144  + -1.00299  ln( TEMP )
THE DETERMINATION FACTOR R-squared =  .934461


TEMP (C)   10      20      25      30      35      37
EXPECTED
   DT     6.54    2.11    1.34    .9      .63     .55

Y = THE CORRESPONDING PROBIT.
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PROGRAM NAME: LOG-PROBIT MODEL

EUSEIUS MESEMBRINUS (DEUTONYMPH)

                                                ----EXPECTED---
TEMP     DT         1/DT        Y          Y          DT
 18      2.67       .375        3.555      3.558      2.683
 22      2.05       .488        3.419      3.363      1.83
 26      1.01       .99         3.091      3.201      1.295
 30      1.08       .926        3.12       3.062      .946

DAY-DEGREE MODEL

     1/DT = -.599294  +  .539118E-01  TEMP
THE DETERMINATION FACTOR R-squared =  .81289
THE THRESHOLD TEMPERATURE     =  11.1162  C


LOG-PROBIT MODEL

PROBIT ( DT ) =  6.36399  + -.970823  ln( TEMP )
THE DETERMINATION FACTOR R-squared =  .880244


TEMP (C)   10      20      25      30      35      37
EXPECTED
   DT     6.9     2.2     1.41    .95     .66     .58

Y = THE CORRESPONDING PROBIT.
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PROGRAM NAME: LOG-PROBIT MODEL

EUSEIUS MESEMBRINUS (TOTAL)

                                          ----EXPECTED---
TEMP     DT        1/DT       Y           Y         DT
 18      11.5      .087       4.343       4.309     11.006
 22      7.47      .134       4.03        4.043     7.611
 26      4.54      .22        3.724       3.821     5.359
 30      4.4       .227       3.706       3.631     3.848

DAY-DEGREE MODEL

     1/DT = -.137316  +  .126836E-01  TEMP
THE DETERMINATION FACTOR R-squared =  .920958
THE THRESHOLD TEMPERATURE      =  10.8263  C


LOG-PROBIT MODEL

PROBIT ( DT ) =  8.14055  + -1.32575  ln( TEMP )
THE DETERMINATION FACTOR R-squared =  .939994


TEMP (C)   10      20      25      30      35      37
EXPECTED
   DT     24.06   9.13    5.84    3.85    2.6     2.24

Y = THE CORRESPONDING PROBIT.
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APPENDIX E

COMPUTER PRINTOUTS OF *Euseius mesembrinus* LIFE TABLES ON DIFFERENT TYPES OF FOOD

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                    LIFE TABLE DATA SHEET       EMONPOL.LIS

THE MITE OR INSECT NAME : EUSEIUS MESEMBRINUS ON ICE PLANT POLLEN
THE TEMPERATURE USED WAS : 26°C

 M      L       X      Mx     Lx     MxLx       RML

17     20     5.75   0.43   0.90    0.382    .093997
56     20     6.75   1.40   0.90    1.260    .242577
61     20     7.75   1.52   0.90    1.372    .207009
54     20     8.75   1.35   0.90    1.215    .143565
45     20     9.75   1.13   0.90    1.012    .093727
48     20    10.75   1.20   0.90    1.080    .078323
42     20    11.75   1.05   0.90    0.945    .053690
34     20    12.75   0.85   0.90    0.765    .034050
28     20    13.75   0.70   0.90    0.630    .021968
22     20    14.75   0.55   0.90    0.495    .013523
16     19    15.75   0.42   0.86    0.360    .007705
10     19    16.75   0.26   0.86    0.225    .003773
10     19    17.75   0.26   0.86    0.225    .002955
 7     19    18.75   0.18   0.86    0.157    .001621
 8     19    19.75   0.21   0.86    0.180    .001451
 1     19    20.75   0.03   0.86    0.023    .000142
 1     19    21.75   0.03   0.86    0.023    .000111
 1     19    22.75   0.03   0.86    0.023    .000087
 1     19    23.75   0.03   0.86    0.023    .000068

THE OBSERVATION (OBS.) INTERVAL USED WAS 1 DAY
THE DEVELOPMENTAL TIME WAS CONSIDERED AS  5.25   INTERVALS
THE SEX RATIO WAS (FEMALES/TOTAL):  .5
THE FRACTION OF EGGS REACHING MATURITY :    .9

THE SUM OF RML                                =  1.00034
THE NET REPRODUCTIVE RATE    (Ro)             =  10.395
THE GENERATION TIME (T) IN OBS. INTERVALS     =  9.59241
THE INTRINSIC RATE OF NATURAL INCREASE (rm) =  .244081
THE FINITE RATE OF INCREASE                   =  1.27645

          COLUMN DEFINITIONS

M    - Total progeny at each interval for all females
L    - Number of females alive
X    - Actual female age (time from egg stage)
Mx   - Female progeny per female
Lx   - Rate of survival
MxLx- Female progeny per female times rate of survival
RML - MxLx times (e raised to the power of (-rm times x))
        (COLUMNS M & L CONTAIN THE INPUT DATA)
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                    LIFE TABLE DATA SHEET       EMOMRD.LIS

THE MITE OR INSECT NAME : EUSIEUS MESEMBRINUS ON P. CITRI
THE TEMPERATURE USED WAS : 26°C

 M      L       X      Mx      Lx      MxLx        RML

 3     20     5.75   0.08    0.90    0.068     .021492
20     20     6.75   0.50    0.90    0.450     .117422
40     20     7.75   1.00    0.90    0.900     .192460
32     20     8.75   0.80    0.90    0.720     .126181
32     20     9.75   0.80    0.90    0.720     .103408
34     20    10.75   0.85    0.90    0.765     .090042
30     20    11.75   0.75    0.90    0.675     .065110
41     19    12.75   1.08    0.86    0.923     .072924
40     17    13.75   1.18    0.76    0.900     .058305
31     17    14.75   0.91    0.76    0.697     .037031
40     17    15.75   1.18    0.76    0.900     .039159
40     17    16.75   1.18    0.76    0.900     .032092
23     17    17.75   0.68    0.76    0.517     .015122
26     17    18.75   0.76    0.76    0.585     .014010
16     17    19.75   0.47    0.76    0.360     .007065
10     17    20.75   0.29    0.76    0.225     .003619
13     17    21.75   0.38    0.76    0.292     .003856
 2     17    22.75   0.06    0.76    0.045     .000486
 1     17    23.75   0.03    0.76    0.022     .000199

THE OBSERVATION (OBS.) INTERVAL USED WAS 1 DAY
THE DEVELOPMENTAL TIME WAS CONSIDERED AS  5.25   INTERVALS
THE SEX RATIO WAS (FEMALES/TOTAL):  .5
THE FRACTION OF EGGS REACHING MATURITY :    .9

THE SUM OF RML                                =  .999984
THE NET REPRODUCTIVE RATE   (Ro)              =  10.665
THE GENERATION TIME (T) IN OBS. INTERVALS     =  11.8923
THE INTRINSIC RATE OF NATURAL INCREASE (rm) =  .199033
THE FINITE RATE OF INCREASE                   =  1.22022

          COLUMN DEFINITIONS

M    - Total progeny at each interval for all females
L    - Number of females alive
X    - Actual female age (time from egg stage)
Mx   - Female progeny per female
Lx   - Rate of survival
MxLx- Female progeny per female times rate of survival
RML - MxLx times (e raised to the power of (-rm times x))
        (COLUMNS M & L CONTAIN THE INPUT DATA)
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                    LIFE TABLE DATA SHEET       EMONTCM.LIS

THE MITE OR INSECT NAME : EUSEIUS MESEMBRINUS ON E. BANKSI
THE TEMPERATURE USED WAS : 26°C

 M       L        X       Mx      Lx      MxLx        RML

13      22      5.90    0.30    0.90     0.266     .086108
34      20      6.90    0.85    0.82     0.695     .186028
43      19      7.90    1.13    0.78     0.880     .194343
43      19      8.90    1.13    0.78     0.880     .160536
40      19      9.90    1.05    0.78     0.818     .123357
34      19     10.90    0.89    0.78     0.695     .086613
34      18     11.90    0.94    0.74     0.695     .071546
22      18     12.90    0.61    0.74     0.450     .038241
14      16     13.90    0.44    0.65     0.286     .020102
16      14     14.90    0.57    0.57     0.327     .018977
 8      14     15.90    0.29    0.57     0.164     .007838
 3      13     16.90    0.12    0.53     0.061     .002428
 5      11     17.90    0.23    0.45     0.102     .003343
 1      11     18.90    0.05    0.45     0.020     .000552
 0      11     19.90    0.00    0.45     0.000     .000000
 1      11     20.90    0.05    0.45     0.020     .000377

THE OBSERVATION (OBS.) INTERVAL USED WAS 1 DAY
THE DEVELOPMENTAL TIME WAS CONSIDERED AS  5.4   INTERVALS
THE SEX RATIO WAS (FEMALES/TOTAL):  .5
THE FRACTION OF EGGS REACHING MATURITY :   .9

THE SUM OF RML                                =  1.00039
THE NET REPRODUCTIVE RATE   (Ro)              =  6.36136
THE GENERATION TIME (T) IN OBS. INTERVALS     =  9.6815
THE INTRINSIC RATE OF NATURAL INCREASE (rm) = .191111
THE FINITE RATE OF INCREASE                   =  1.21059

          COLUMN DEFINITIONS

M    - Total progeny at each interval for all females
L    - Number of females alive
X    - Actual female age (time from egg stage)
Mx   - Female progeny per female
Lx   - Rate of survival
MxLx- Female progeny per female times rate of survival
RML - MxLx times (e raised to the power of (-rm times x))
        (COLUMNS M & L CONTAIN THE INPUT DATA)
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                    LIFE TABLE DATA SHEET       EMON6SM.LIS

THE MITE OR INSECT NAME : EUSEIUS MESEMBRINUS ON E. SEXMACULATUS
THE TEMPERATURE USED WAS : 26°C

 M      L       X       Mx      Lx      MxLx        RML

19     25     5.75    0.38    0.90    0.342      .131927
26     25     6.75    0.52    0.90    0.468      .152970
30     25     7.75    0.60    0.90    0.540      .149557
42     25     8.75    0.84    0.90    0.756      .177415
35     24     9.75    0.73    0.86    0.630      .125274
30     22    10.75    0.68    0.79    0.540      .090985
21     20    11.75    0.52    0.72    0.378      .053966
20     20    12.75    0.50    0.72    0.360      .043550
16     19    13.75    0.42    0.68    0.288      .029521
 8     17    14.75    0.24    0.61    0.144      .012507
11     16    15.75    0.34    0.58    0.198      .014572
 6     14    16.75    0.21    0.50    0.108      .006735
 5     14    17.75    0.18    0.50    0.090      .004755
 4     14    18.75    0.14    0.50    0.072      .003224
 3     10    19.75    0.15    0.36    0.054      .002049
 2     10    20.75    0.10    0.36    0.036      .001157

THE OBSERVATION (OBS.) INTERVAL USED WAS 1 DAY
THE DEVELOPMENTAL TIME WAS CONSIDERED AS  5.25   INTERVALS
THE SEX RATIO WAS (FEMALES/TOTAL):  .5
THE FRACTION OF EGGS REACHING MATURITY :   .9

THE SUM OF RML                                =  1.00016
THE NET REPRODUCTIVE RATE   (Ro)              =  5.004
THE GENERATION TIME (T) IN OBS. INTERVALS     =  9.71995
THE INTRINSIC RATE OF NATURAL INCREASE (rm)  =  .165663
THE FINITE RATE OF INCREASE                   =  1.18018

          COLUMN DEFINITIONS

M    - Total progeny at each interval for all females
L    - Number of females alive
X    - Actual female age (time from egg stage)
Mx   - Female progeny per female
Lx   - Rate of survival
MxLx- Female progeny per female times rate of survival
RML - MxLx times (e raised to the power of (-rm times x))
        (COLUMNS M & L CONTAIN THE INPUT DATA)
```

BIOGRAPHICAL SKETCH

Mohamed M. Abou-Setta was born in Giza, Egypt, on January 28, 1947. He was raised in the same city and graduated from El-Saidya Secondary School in 1963. He attended the University of Ain-Shams, Faculty of Agriculture and received the Bachelor of Science degree in 1967, with a major in Economic Entomology. He was drafted into the Egyptian army in 1968 and served on active duty for more than 6 years until 1974. He was hired in 1968 by the Egyptian Government in the Plant Protection Research Institute and is currently on a leave of absence. In 1981, he received his Master of Science degree from the University of Ain-Shams. His research involved chemical control of scale insects on citrus and spray application evaluations.

Mohamed came to the United States in October 1983 as an Amideast Peace Fellow for 20 months to conduct a Ph.D. research program with Dr. Carl C. Childers (IFAS-CREC, Lake Alfred, FL). He entered graduate school at the University of Florida in May 1985. He was able to continue his study for the degree with a research assistantship.

Mohamed is married to Nadia Sedeek and has a daughter, Abeer, and son, Ahmed. Mohamed served as president of the Egyptian Student Association at the University of Florida during 1986-1987 and 1987-1988. He also served as vice-president of the Moslem Student Association at the University of Florida during 1986-1987.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Harvey L Cromroy

Harvey L. Cromroy, Chairman
Professor, Entomology and Nematology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Carl C. Childers

Carl C. Childers, Cochairman
Associate Professor, Entomology
and Nematology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Jon C. Allen

Jon C. Allen
Associate Professor, Entomology
and Nematology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dale H Habeck

Dale H. Habeck
Professor, Entomology and Nematology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Mohamed A Ismail

Mohamed A. Ismail
Professor, Horticultural Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Harold A. Denmark

Harold A. Denmark
Chief Entomologist, Florida Division
of Plant Industry

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December, 1988

Dean, College of Agriculture

Dean, Graduate School